NBSIR 82-2495

Conservation and Substitution Technology for Critical Materials Volume II

Proceedings of Public Workshop sponsored by
U.S. Department of Commerce/National Bureau of Standards
and U.S. Department of the Interior/Bureau of Mines

15-17 June 1981

Vanderbilt University
Nashville, TN

April 1982

DEPARTMENT OF COMMERCE * NATIONAL BUREAU OF STANDARDS *

U.S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

-- 1 OF 1

-- ***DTIC DOES NOT HAVE THIS ITEM***

-- 1 - AD NUMBER: D439713

-- 5 - CORPORATE AUTHOR: NATIONAL BUREAU OF STANDARDS WASHINGTON DC CENTER
-- FOR MATERIALS SCIENCE*

-- 6 - UNCLASSIFIED TITLE: CONSERVATION AND SUBSTITUTION TECHNOLOGY
-- FOR CRITICAL MATERIALS. VOLUME II

--10 - PERSONAL AUTHORS: GRAY,A. G. ;

--11 - REPORT DATE: APR , 1982

--12 - PAGINATION: 488P

--14 - REPORT NUMBER: NBSIR-82-2495

--20 - REPORT CLASSIFICATION: UNCLASSIFIED

--21 - SUPPLEMENTARY NOTE: PROCEEDINGS OF PUBLIC WORKSHOP SPONSORED BY
-- U.S. DEPT. OF COMMERCE/NATIONAL BUREAU OF STANDARDS AND U.S. DEPT.
-- OF THE INTERIOR/BUREAU OF MINES, HELD AT VANDERBILT UNIV. NASHVILLE,
-- TN, 15-17 JUNE 1981.

--22 - LIMITATIONS (ALPHA): APPROVED FOR PUBLIC RELEASE; DISTRIBUTION
-- UNLIMITED. ~~AVAILABILITY: NATIONAL TECHNICAL INFORMATION SERVICE~~,
-- ~~SPRINGFIELD, VA. 22161. NBSIR-82-2495~~

--33 - LIMITATION CODES: 1 [redacted]

-- END Y FOR NEXT ACCESSION END

NBSIR 82-2495

CONSERVATION AND SUBSTITUTION TECHNOLOGY FOR CRITICAL MATERIALS VOLUME II

Proceedings of Public Workshop sponsored by
U.S. Department of Commerce/National Bureau of Standards
and U.S. Department of the Interior/Bureau of Mines

15-17 June 1981

Vanderbilt University
Nashville, TN

General Chairman:

Allen G. Gray
American Society for Metals
Adjunct Professor of Metallurgy
Vanderbilt University

Workshop Coordinator:

Robert T. Nash
School of Engineering
Vanderbilt University
Nashville, TN

April 1982

U.S. DEPARTMENT OF COMMERCE, Malcolm Baldrige, *Secretary*
NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Director*

PL-48501 (Conf-as-a-whole)

TABLE OF CONTENTS

VOLUME II

Technological Opportunities for Conservation of Critical Metals Utilizing Metallurgical Coating Systems

Opportunities for Conservation and Substitution of Critical Metals Utilizing Rapid Solidification Technology and Near Net Shape Processing

56
-23
33

A PRESENTATION AT THE "WORKSHOP ON CONSERVATION AND SUBSTITUTION TECHNOLOGY FOR CRITICAL MATERIALS"

David S. Duvall
Pratt & Whitney Aircraft Div.

KEYNOTE TALK

Opportunities for Conservation of Critical Metals Utilizing Metallurgical Coating Systems

A Presentation At The
"Workshop on Conservation and Substitution Technology for Critical Materials"

Nashville, Tennessee
June 15-17, 1981

By

D.S. Duvall
Supervisor, Coating Development
Pratt and Whitney Aircraft
Chairman, High Alloys Committee
Welding Research Council

INTRODUCTION

A NUMBER OF UNITED STATES INDUSTRIES FIND THEMSELVES DEPENDENT ON USAGE OF MATERIALS WHICH, BECAUSE OF THEIR LIMITED OR TENUOUS AVAILABILITY, ARE LABELED "CRITICAL" OR "STRATEGIC" ELEMENTS. CONSEQUENTLY, CONSIDERABLE THOUGHT IS PRESENTLY FOCUSED ON MEANS OF REDUCING OUR DEPENDENCE ON THESE ELEMENTS. A DIFFICULT TASK -- FOR OUR ADDICTION IS CEMENTED BY THE DEMONSTRATED BENEFITS OF THESE ELEMENTS IN ENHANCING MATERIAL PERFORMANCE IN A VARIETY OF WAYS ... STRENGTH....SURFACE STABILITY....EROSION RESISTANCE....PROTECTION AGAINST WEAR.

AS AN EXAMPLE, A MODERN GAS TURBINE POWERPLANT FOR AIRCRAFT PROPULSION-- THE F100 ENGINE USED TO POWER THE U.S. AIR FORCE F-15 AND F-16 FIGHTER AIRCRAFT -- IS DEPENDENT ON MANY "CRITICAL" MATERIALS. BUILDING THIS ENGINE REQUIRES ALLOYS CONSTRUCTED OF SIGNIFICANT AMOUNTS OF ELEMENTS DEEMED "STRATEGIC" BECAUSE OF THEIR EXTERNAL (AND POTENTIALLY VULNERABLE) SOURCES OF SUPPLY (FIGURE 1):

- NICKEL - 5204 LBS.
- TITANIUM - 5366 LBS.
- CHROMIUM - 1656 LBS.
- COBALT - 910 LBS.
- COLUMBIUM - 171 LBS.
- TANTALUM - 3 LBS.

TITANIUM'S BENEFITS ARE WELL KNOWN -- AN ELEMENT EXTENDING LIGHTWEIGHT MATERIAL USAGE TO 1100°F AND ABOVE. NICKEL, CHROMIUM, AND COBALT ARE CORE ELEMENTS OF THE "SUPERALLOY" CLASS OF HEAT RESISTANT MATERIALS

WHICH PROVIDE LONG LIFE SERVICE AT TEMPERATURES UP TO 2000°F AND ABOVE. COLUMBIUM AND TANTALUM ENHANCE SUPERALLOY BEHAVIOR. IN COOLER PORTIONS OF THE ENGINE, CHROMIUM-CONTAINING ALLOYS AND COATINGS PROVIDE CORROSION PROTECTION WHILE COBALT, CHROMIUM, TANTALUM AND TUNGSTEN (ANOTHER STRATEGIC ELEMENT) ARE EMPLOYED IN HARDFACING DEPOSITS WHICH IMPART WEAR RESISTANCE.

THE EFFECT OF A LONG TERM CUT-OFF IN THE SUPPLY OF ONE OR MORE OF THESE CRITICAL ELEMENTS IS SEEN FROM THE FOLLOWING EXAMPLE. DURING 1979, APPROXIMATELY 83% OF ALL COMMERCIAL AIRLINE FLIGHTS IN THE UNITED STATES WERE IN AIRCRAFT POWERED BY THE PRATT & WHITNEY JT8D ENGINE. A CUT-OFF IN COBALT SUPPLIES WOULD EXHAUST THE PIPELINE OF SPARE PARTS SUCH AS THE FIRST STAGE TURBINE VANE (WHICH CONTAINS 60 PERCENT COBALT) IN ABOUT 12 MONTHS. AT THAT POINT, THE JT8D POWERED FLEET WOULD START TO BE GROUNDED AT THE RATE OF 25 PERCENT PER YEAR UNLESS SATISFACTORY ALTERNATE MATERIALS WERE FLIGHT QUALIFIED AND "WAITING ON THE SHELF".

TO REDUCE OUR VULNERABILITY, WE BELIEVE THAT A CONCERTED EFFORT WILL BE REQUIRED BY THE GOVERNMENT, PRODUCERS, AND USERS OF STRATEGIC MATERIALS IN THE FOLLOWING AREAS (FIGURE 2):

- SUBSTITUTION
- CONSERVATION
- INCREASED DOMESTIC PRODUCTION
- IMPROVED USAGE OF NATIONAL STOCKPILES

IN ADDITION, INFORMATION IS NEEDED ON THE POTENTIAL UTILITY OF METHODS LESS CONVENTIONAL THAN DIRECT ELEMENTAL OR ALLOY SUBSTITUTION. IN ESSENCE, WE NEED TO ENHANCE OUR PREPAREDNESS THROUGH "STOCKPILING" ALTERNATE TECHNICAL APPROACHES.

EFFECT OF STRATEGIC ELEMENTS ON SURFACE PROPERTIES

ONE SUCH APPROACH INVOLVES TREATMENTS TO METALLURGICALLY MODIFY MATERIAL SURFACES -- RESTRICTING USE OF CRITICAL ELEMENTS TO SURFACE LAYERS ONLY, FOR EXAMPLE. STRATEGIC ELEMENTS ARE WIDELY USED TODAY TO IMPROVE ALLOY SURFACE PROPERTIES IN OXIDATION, CORROSION, EROSION, AND WEAR (FIGURE 3). CHROMIUM, COBALT, AND TANTALUM GREATLY INCREASE THE HIGH TEMPERATURE OXIDATION AND HOT CORROSION RESISTANCE OF SUPERALLOYS. FIGURE 4 ILLUSTRATES THE INCREASED OXIDATION AND HOT CORROSION RESISTANCE OF PRATT & WHITNEY AIRCRAFT'S NEW TANTALUM CONTAINING SINGLE CRYSTAL TURBINE AIRFOIL ALLOY 454 COMPARED TO MAR-M 200+HF -- A CURRENT TANTALUM-FREE TURBINE AIRFOIL ALLOY. IT IS ALSO WELL KNOWN THAT IRON, NICKEL, AND COBALT ALLOYS NEED APPRECIABLE AMOUNTS OF CHROMIUM TO RESIST LOWER TEMPERATURE CORROSION.

AN ALTERNATE APPROACH (FIGURE 5) FOR ACHIEVING SUITABLE SURFACE STABILITY IS TO COAT, CLAD, OR OTHERWISE METALLURGICALLY MODIFY THE EXPOSED SURFACES REQUIRING PROTECTION. IN THE IDEAL CASE, COMPONENTS EXPOSED TO HARSH ENVIRONMENTS COULD BE CONSTRUCTED OF "STRATEGIC-METAL-LEAN" STRUCTURAL ALLOYS LEAVING ONLY A SMALL QUANTITY OF CRITICAL ELEMENT(S) TO BE CONCENTRATED AT OUTER LAYERS. THE BENEFITS

OF SUCH AN APPROACH WOULD BE CONSIDERABLE -- ALLOWING SUBSTANTIAL CONSERVATION OF STRATEGIC MATERIALS. HOWEVER, IT MUST ALSO BE RECOGNIZED THAT THIS METHOD INTRODUCES RISKS OR PERCEIVED RISKS SINCE SUBSTANTIVE FIELD EXPERIENCE DOES NOT EXIST WITH THIS APPROACH IN MANY APPLICATIONS.

THE PRINCIPAL CONCERN IS THE CONSEQUENCE OF DEFEAT OR PREMATURE REMOVAL (SPALLING, ETC.) OF THE SURFACE LAYER. WOULD SUCH A LOSS LEAD TO RAPID ATTACK OF THE UNDERLYING STRUCTURAL MATERIAL AND RESULT IN A CATASTROPHIC FAILURE OF THE COMPONENT? TO BE ACCEPTABLE, THE SURFACE TREATMENT APPROACH REQUIRES CONSIDERABLE FORETHOUGHT. ALSO, A BASE OF EXPERIENCE IS NEEDED FROM WHICH TO DRAW CONFIDENCE IN SURFACE LAYER PERFORMANCE DURING SERVICE.

MATERIAL SURFACE MODIFICATIONS - CURRENT STATUS

FORTUNATELY, CONSIDERABLE EXPERIENCE ALREADY EXISTS THROUGH THE LONG-TIME, WIDESPREAD, AND GROWING USE OF SURFACE TREATMENTS IN MANY INDUSTRIES AND A VARIETY OF PROCESSES FOR CREATING THEM. SURFACE TREATMENTS RANGING IN THICKNESS FROM ANGSTROMS TO INCHES ARE PRESENTLY UTILIZED TO EITHER REDUCE COST (ALLOWING USE OF LESS EXPENSIVE STRUCTURAL ALLOYS) OR TO ENHANCE RESISTANCE AGAINST OXIDATION, CORROSION, EROSION, OR WEAR. FOR INSTANCE, THIN (ANGSTROMS OR MICRONS) DEPOSITS OF CHROMIUM PROVIDE PROTECTION FOR AUTOMOTIVE COMPONENTS AND ALLEVIATE THE NEED FOR MORE EXPENSIVE STAINLESS STEELS. AT THE OTHER EXTREME, LARGE COMPONENTS SUCH AS FLUE GAS SCRUBBERS FOR ELECTRIC POWERPLANTS ARE NOW BEING FABRICATED BY EXPLOSIVELY CLADDING 1/8-1/2 INCH LAYERS OF STAINLESS STEELS OR NICKEL-CHROMIUM ALLOYS TO

THE SURFACES OF CARBON STEEL STRUCTURES TO PROVIDE CORROSION RESISTANCE AT REDUCED COST.

IN TODAY'S AIRCRAFT GAS TURBINE POWERPLANT, METALLURGICAL COATINGS AND SURFACE TREATMENTS ARE EXTENSIVELY EMPLOYED NOT SO MUCH TO REDUCE COST BUT TO MAXIMIZE THE SURFACE STABILITY OF THE BEST STRUCTURAL ALLOYS AVAILABLE (FIGURE 6). TAILORED SURFACE COMPOSITIONS ARE USED ON AIRFOILS IN THE HIGH PRESSURE TURBINE SECTION TO INCREASE OXIDATION AND HOT CORROSION RESISTANCE. CERAMIC COATINGS PROVIDE THERMAL INSULATION FOR COMBUSTOR AND AFTERBURNER COMPONENTS. HARDFACE DEPOSITS ARE USED THROUGHOUT THE ENGINE TO RESIST A VARIETY OF FORMS OF WEAR. ALSO, ELECTROPLATED LAYERS (E.G., NICKEL-CADMIUM) ARE USED TO RESIST CORROSIVE ATTACK IN LOWER TEMPERATURE ENGINE REGIMES.

IT IS WORTHWHILE TO EXAMINE CURRENT GAS TURBINE ENGINE SURFACE TREATMENTS IN MORE DETAIL TO APPRECIATE TODAY'S STATE-OF-THE-ART IN THIS TECHNOLOGY. FOR EXAMPLE, METALLURGICAL COATINGS HAVE BEEN EMPLOYED SINCE THE EARLY 1960'S TO RETARD OXIDATION AND HOT CORROSION OF TURBINE AIRFOILS. IMPROVEMENTS IN COMPONENT LIVES UP TO A FACTOR OF TEN OR MORE HAVE BEEN REALIZED BY THESE TREATMENTS. INITIALLY, THEY CONSISTED OF SURFACE ENRICHMENT IN ALUMINUM AND/OR CHROMIUM BY DIFFUSION PROCESSES (FIGURE 7). SUBSEQUENT ADVANCES IN ALLOY DEVELOPMENT (I.E., DIRECTIONAL SOLIDIFICATION, SINGLE CRYSTALS) HAS LED TO A GENERATION OF TURBINE AIRFOIL MATERIALS WHOSE MECHANICAL PROPERTIES FAR OUTSTRIP THEIR CAPABILITY TO RESIST HIGH TEMPERATURE SURFACE DEGRADATION.

IMPROVED COATINGS WERE NEEDED IN ORDER TO FULLY UTILIZE THE HIGH TEMPERATURE CAPABILITY OF THOSE NEW MATERIALS; THIS LED TO THE DEVELOPMENT OF A FAMILY OF 3-10 MILS THICK VAPOR DEPOSITED OVERLAY

COATINGS WITH COMPOSITIONS TAILORED TO ACHIEVE THE MAXIMUM ATTAINABLE ENVIRONMENTAL RESISTANCE. THESE COATINGS, KNOWN AS MCRALY'S (WHERE M=NICKEL, COBALT AND/OR IRON, CR=CHROMIUM, AL=ALUMINUM, AND Y=YTTRIUM) PROVIDE UP TO 10 TIMES THE PROTECTION AVAILABLE WITH PREVIOUS SURFACE-DIFFUSION-ENRICHED TREATMENTS. TODAY, MOST HIGH-PRESSURE TURBINE BLADES AND VANES IN MILITARY AND COMMERCIAL GAS TURBINE ENGINES ARE PROTECTED BY SURFACE DIFFUSION OR OVERLAY COATINGS; YET IMPROVEMENTS IN THE DURABILITY OF THESE SURFACE TREATMENTS COULD BE IMMEDIATELY TRANSLATED INTO BETTER ENGINE PERFORMANCE AND COMPONENT LIFE.

WE HAVE ALSO EMPLOYED PLASMA SPRAYED CERAMIC COATINGS FOR MANY YEARS TO THERMALLY INSULATE SHEET METAL COMPONENTS IN COMBUSTOR AND AFTER-BURNER COMPONENTS (FIGURE 8). THESE "THERMAL BARRIERS" TYPICALLY CONSIST OF APPROXIMATELY 5 MILS OF AN OXIDATION-RESISTANT METALLIC UNDERLAYER COVERED BY 10-20 MILS OF A ZIRCONIA COMPOSITION OR A MIXTURE OF THE METALLIC AND CERAMIC CONSTITUENTS. THESE COATINGS HAVE GREATLY EXTENDED THE LIFE OF THE CHROMIUM AND COBALT-RICH MATERIALS USED IN THESE APPLICATIONS. EVEN MORE SIGNIFICANT BENEFITS COULD BE ACHIEVED BY EXTENSION OF THIS TECHNOLOGY TO TURBINE SECTION AIRFOILS.

TODAY'S GAS TURBINE ENGINE ALSO PROVIDES MANY OPPORTUNITIES FOR METAL-TO-METAL WEAR, WHICH, IF UNCHECKED, CAN LEAD TO LOSS OF PERFORMANCE, PREMATURE COMPONENT LIFE, OR PART FAILURE. WEAR-RESISTANT SURFACE TREATMENTS HAVE BEEN SUCCESSFULLY UTILIZED SINCE

THE INTRODUCTION OF JET ENGINES TO COMBAT THIS PROBLEM (FIGURE 9). MANY OF THESE TREATMENTS INVOLVE SURFACE DEPOSITS OF CERMETS CONSISTING OF CHROMIUM, TUNGSTEN, OR TANTALUM CARBIDES IN A COBALT MATRIX. THEY ARE TYPICALLY FABRICATED BY WELDING OR THERMAL SPRAYING. THESE ARE LONG-PRACTICED EXAMPLES OF STRATEGIC-METAL-RICH SURFACE TREATMENTS GUARDING STRUCTURAL ALLOY LIFE; YET THE BIGGEST CHALLENGE TODAY IN THIS TECHNOLOGY IS TO REDUCE THE CRITICAL-METAL CONTENT (AND COST) OF THESE WEAR RESISTANT MATERIALS.

IN THE COOLER PORTIONS OF TODAY'S AIRCRAFT GAS TURBINE, SEVERAL COMPONENTS ARE DEPENDENT ON THIN SURFACE COATINGS TO PROVIDE PROTECTION AGAINST AQUEOUS CORROSION. ELECTROPLATED OR SLURRY SPRAYED LAYERS OF NICKEL-CADMIUM, CHROMIUM, OR ALUMINUM PREVENT SURFACE ATTACK OF CRITICAL STRUCTURES SUCH AS SHAFTS AND COMPRESSOR BLADES AND VANES. IN MANY CASES, HOWEVER, THE COMPONENT BEING PROTECTED IS AN IRON OR NICKEL ALLOY ALREADY CONTAINING A SUBSTANTIAL AMOUNT OF CHROMIUM TO PROVIDE INHERENT ENVIRONMENTAL RESISTANCE INDEPENDENT OF SURFACE ALLOYING. THIS IS ANOTHER EXAMPLE OF THE CURRENT DESIGN APPROACH WHICH AIMS TO ACHIEVE THE MAXIMUM DURABILITY PLUS SAFETY MARGINS POSSIBLE BY USE OF ALL THE BEST AVAILABLE MATERIALS.

SURFACE TREATMENTS TO REDUCE STRATEGIC MATERIAL CONSUMPTION

THE WIDESPREAD, SUCCESSFUL USE OF SURFACE TREATMENTS PROVIDES A CONFIDENCE BASE FOR EXTENSION OF THIS APPROACH TO FUTURE CONSERVATION OF STRATEGIC MATERIALS IN MANY INDUSTRIES. IN JET ENGINES,

SEVERAL OPPORTUNITIES EXIST TO REDUCE CRITICAL MATERIALS IN TURBINE STRUCTURES THROUGH RELIANCE ON SURFACE COATINGS. THIS WILL REQUIRE, HOWEVER, A PHILOSOPHICAL CHANGE TO A CONCEPT WHICH ACCEPTS ONLY ONE BARRIER AGAINST ENVIRONMENTAL OR SURFACE ATTACK. OBVIOUSLY, THE BENEFITS OF SUCH AN APPROACH MUST BE EXTREMELY PERSUASIVE TO OVERRULE PRESENT DESIGN PRACTICE.

THE RECENT COBALT AND TANTALUM SHORTAGES HAVE ALREADY AFFECTED SURFACE TREATMENT TECHNOLOGY. A CONSIDERABLE EFFORT IS UNDERWAY, FOR INSTANCE, TO REDUCE THE COBALT CONTENT OF PRESENT WEAR-RESISTANT SURFACE ALLOYS. NEW HARDFACING COMPOSITIONS HAVE BEEN FORMULATED WITH NICKEL RATHER THAN COBALT MATRICES. THE TANTALUM CARBIDES IN THESE WEAR-RESISTANT ALLOYS AND IN CUTTING MATERIALS HAVE ALREADY BEEN REPLACED IN SOME INSTANCES BY TITANIUM CARBIDES AND/OR NITRIDES, AND THROUGH USE OF MOLYBDENUM AS AN ALTERNATE REFRACTORY METAL ADDITION.

IN THE AREA OF OXIDATION AND HOT CORROSION RESISTANCE, PRATT & WHITNEY AIRCRAFT IS EVALUATING THE SUBSTITUTION OF A NICOCRALY TURBINE AIRFOIL COATING (23% COBALT) TO REPLACE A CURRENTLY USED COCRALY (67% COBALT) COMPOSITION (FIGURE 10). LABORATORY AND EXPERIMENTAL GROUND-BASED ENGINE TESTS TO DATE HAVE BEEN SUCCESSFUL, AND TURBINE AIRFOILS COATED WITH THE LOWER COBALT ALLOY ARE PRESENTLY UNDERGOING FIELD SERVICE EVALUATION WITH COMMERCIAL AIRLINES. IF THE SUBSTITUTE COATINGS' DURABILITY IS VERIFIED, A YEARLY SAVINGS OF 10,000-20,000 LBS. OF COBALT COULD BE REALIZED -- A MODEST BUT

INTERESTING CONSERVATION IN A MATERIAL EMPLOYED AS A 5 MIL THICK LAYER.

THE GREATEST POTENTIAL EXISTS, OF COURSE, IN USING SURFACE TREATMENTS IN CONJUNCTION WITH STRATEGIC-METAL-LEAN STRUCTURAL ALLOYS. WE ARE PRESENTLY EXAMINING CONCEPTS TO IMPART OXIDATION AND HOT CORROSION RESISTANCE TO POTENTIAL TURBINE AIRFOIL MATERIALS WHICH HAVE LOW CRITICAL MATERIAL CONTENT. PRELIMINARY EXPERIMENTS, USING TAILORED METALLIC COATINGS, HAVE BEEN PROMISING, BUT CONSIDERABLE DEVELOPMENT IS REQUIRED BEFORE SUCH A SYSTEM CAN BE UTILIZED.

CERAMIC THERMAL BARRIER COATINGS ALSO OFFER A MEANS TO MAINTAIN HEAT RESISTANCE WHILE REDUCING CRITICAL METAL CONTENT IN TURBINE COMPONENTS. THIN (E.G. 5-20 MILS) LAYERS OF CERAMICS SUCH AS ZIRCONIA CAN REDUCE THE TEMPERATURE OF AIR-COOLED TURBINE AIRFOILS BY AS MUCH AS 300^{O}F (FIGURE 11). IN THEORY, THIS AMOUNT OF INSULATION CAN BE TRANSLATED INTO A REQUIREMENT FOR UP TO 300^{O}F LESS HEAT RESISTANCE (STRENGTH, ENVIRONMENTAL RESISTANCE) IN THE UNDERLYING STRUCTURAL ALLOY. POTENTIALLY, CRITICAL-ELEMENT ALLOYING ADDITIONS COULD BE CORRESPONDINGLY REDUCED.

THE RISKS OF SUCH AN APPROACH ARE OBVIOUS; HOWEVER, FAILURE OF THE CERAMIC COATING COULD LEAD TO RAPID OVERHEATING. SEVERAL PROGRAMS ARE CURRENTLY BEING CONDUCTED UNDER INDUSTRY AND GOVERNMENT SPONSORSHIP TO INCREASE THE RELIABILITY OF CERAMIC GAS TURBINE COATINGS. AT PRATT & WHITNEY AIRCRAFT, WE HAVE BEEN ABLE TO INCREASE

THE RESISTANCE TO CERAMIC SPALLING UNDER HARSH TURBINE AIRFOIL CONDITIONS FROM A FEW HUNDRED THERMAL CYCLES TO UPWARDS OF 20,000 CYCLES. NEVERTHELESS, CONSIDERABLY MORE EXPERIENCE AND CONFIDENCE ARE REQUIRED BEFORE THERMAL BARRIER COATINGS CAN BE USED AS A SUBSTITUTE FOR TODAY'S STRATEGIC-ELEMENT RICH SUPERALLOYS.

AS PREVIOUSLY DISCUSSED, PROTECTION FROM AQUEOUS CORROSION CAN BE ACHIEVED THROUGH CHROMIUM-RICH SURFACE TREATMENTS. A REVISITATION OF THIS APPROACH IS ILLUSTRATED IN FIGURE 12. UP TILL NOW, HOWEVER, THIS TECHNIQUE HAS BEEN VIEWED AS A "CHEAP" SUBSTITUTE -- BE IT IN A WIDESPREAD CONSUMER PRODUCT OR A HIGH TECHNOLOGY DEVICE. IN GAS TURBINE CONSTRUCTION, CHROMIUM SURFACE ENRICHMENT HAS GENERALLY BEEN UTILIZED TO ENHANCE THE DURABILITY OF ALREADY RESISTANT MATERIALS. A CHANGE TO COMPLETE DEPENDENCE ON CHROMIUM-RICH SURFACES WOULD PROVIDE SUBSTANTIAL SAVINGS OF A CRITICAL ELEMENT BUT, LIKE CERAMIC THERMAL BARRIER COATINGS, NEEDS CONSIDERABLY GREATER CONFIDENCE IN RELIABILITY THAN EXISTS TODAY.

THE POTENTIAL FOR WEAR-RESISTANT SURFACE TREATMENTS TO REDUCE STRATEGIC-METAL USAGE IN GAS TURBINES APPEARS RATHER LIMITED SINCE SURFACE DEPOSITS ARE ALREADY THE PRINCIPAL MEANS OF COMBATING SUCH PROBLEMS. THERE ARE A FEW APPLICATIONS, HOWEVER, WHERE NEW METALLURGICAL OR CERAMIC COATINGS MAY BE BENEFICIAL. AS AN EXAMPLE, PRATT & WHITNEY AIRCRAFT CURRENTLY UTILIZES A COBALT-BASE ALLOY AS A SEAL MATERIAL BETWEEN ROTATING HIGH-PRESSURE TURBINE BLADES AND THE

EXTERNAL ENGINE CASE (FIGURE 13). A RECOGNIZED ADVANTAGE OF THIS SEAL MATERIAL IS THE "LUBRICITY" OF THE COBALT OXIDE IT FORMS AS OPPOSED TO THE OXIDES WHICH WOULD BE CREATED ON ALTERNATE HEAT-RESISTANT MATERIALS BASED ON NICKEL. IF A COBALT-RICH SURFACE TREATMENT WAS SUBSTITUTED TO PROVIDE THE DESIRED "LUBRICITY", WE ESTIMATE THAT A YEARLY SAVINGS OF APPROXIMATELY 20,000 LBS. OF COBALT WOULD BE ACHIEVED IN PRATT & WHITNEY AIRCRAFT ENGINES ALONE.

SURFACE TREATMENTS MAY ALSO BE ABLE TO CONSERVE CRITICAL ELEMENTS BY PROVIDING RESISTANCE TO PARTICULATE EROSION. A PROGRAM IS PRESENTLY BEING CONDUCTED UNDER NASA SPONSORSHIP TO DEVELOP COATINGS TO RETARD JET ENGINE COMPRESSOR AIRFOIL EROSION -- LOSS OF MATERIAL WHICH DEGRADES ENGINE EFFICIENCY AND REQUIRES REPLACEMENT OF THESE TITANIUM, IRON-CHROMIUM, AND NICKEL-CHROMIUM COMPONENTS. THIS EROSION PROBLEM MAY BECOME MORE SERIOUS IN THE FUTURE IF ELECTRICAL GENERATING TURBOMACHINERY USE COAL-DERIVED FUEL CONTAINING SIGNIFICANT PARTICULATE MATTER. FIGURE 14 SHOWS THE DIFFERENCE IN THE AMOUNT OF METAL LOSS BETWEEN COBALT-TUNGSTEN CARBIDE COATED AND UNCOATED TITANIUM COMPRESSOR BLADES AFTER EXPOSURE IN A LABORATORY EROSION TEST. IT IS PROJECTED THAT SUCH COATINGS COULD DOUBLE COMPRESSOR AIRFOIL LIFE. ESTIMATES SUGGEST THAT THIS IMPROVEMENT WOULD DECREASE THE YEARLY AMOUNTS OF TITANIUM AND CHROMIUM NEEDED TO MAKE REPLACEMENT HIGH COMPRESSOR BLADES FOR THE JT8D AND JT9D AIRCRAFT ENGINES BY ROUGHLY 90,000 LBS. AND 10,000 LBS., RESPECTIVELY. IN OTHER ENGINES, THE RELATIVE SAVINGS OF TITANIUM AND CHROMIUM WOULD VARY DEPENDING ON THE RATIO OF TITANIUM TO STEEL OR NICKEL COMPRESSOR BLADES.

HOWEVER, BEFORE SUCH COATINGS CAN BE EMPLOYED, IT MUST BE DEMONSTRATED THAT THEY WILL NOT COMPROMISE COMPONENT MECHANICAL PROPERTIES SUCH AS FATIGUE STRENGTH. AS WITH THE OTHER EXAMPLES DISCUSSED, USE OF EROSION-RESISTANT SURFACE TREATMENTS TO CONSERVE STRATEGIC MATERIAL USAGE WILL BE DEPENDENT ON CONFIDENCE THAT THE INTEGRITY OF THE BASIC STRUCTURE WILL NOT BE IMPAIRED.

RECOMMENDATIONS

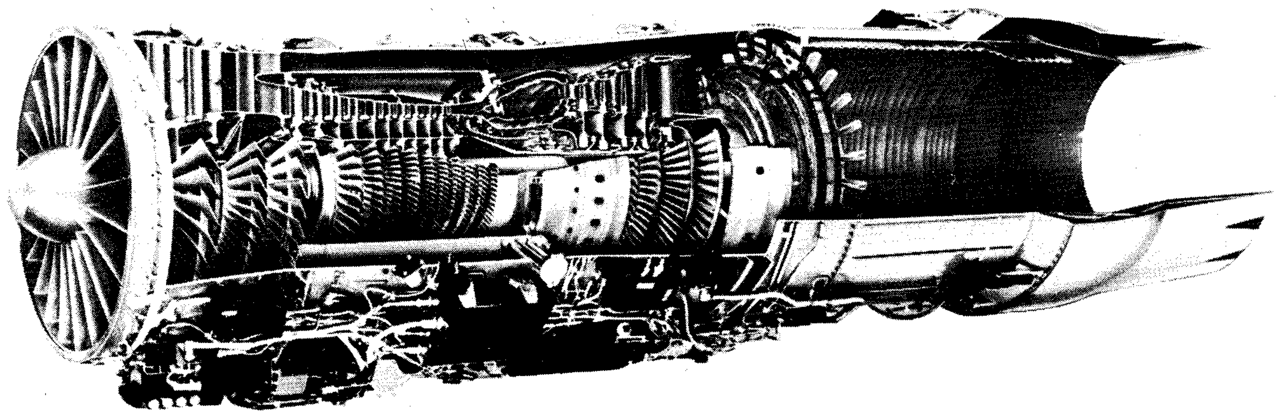
SEVERAL MATERIALS SUBSTITUTIONS HAVE OCCURRED THROUGHOUT INDUSTRY SINCE THE RECENT COBALT AND TANTALUM SHORTAGES. FORTUNATELY, THE RECENT CRISIS HAS PERMITTED TIME FOR INCORPORATION OF SUBSTITUTIONS. THIS LUXURY WOULD NOT EXIST, OBVIOUSLY, IN THE EVENT OF A COMPLETE CUT-OFF OF A STRATEGIC ELEMENT SUPPLY.

THE RECENT DISRUPTIONS OF IMPORTED FUEL AND MINERAL SUPPLIES FOREWARN OF THE NEED TO PREPARE AGAINST POSSIBLE COMPLETE CUTOFFS -- SUDDEN SHOCKS WHICH COULD NOT BE DAMPENED BY SUPPLY/DEMAND ADJUSTMENTS. FOR MANY PRODUCTS, THE LONG LEAD TIMES NEEDED TO VALIDATE SUBSTITUTE MATERIALS WOULD RESULT IN PRODUCTION STOPPAGE, NOT SHORTAGES. "STOCKPILING" OF DEMONSTRATED ALTERNATIVES WOULD PROVIDE ONE CUSHION AGAINST SUCH AN ECONOMIC OR STRATEGIC CRISIS. METALLURGICAL SURFACE TREATMENTS CAN BE AN IMPORTANT PART OF SUCH A STOCKPILE (FIGURE 15).

AS PREVIOUSLY POINTED OUT, RELIABILITY WILL BE THE KEY QUESTION GOVERNING USE OF A PARTICULAR SURFACE TREATMENT TO REPLACE OR

CONSERVE STRATEGIC ELEMENTS IN UNDERLYING STRUCTURAL ALLOYS. DEMONSTRATED CONFIDENCE WOULD BE NEEDED AT THE ONSET OF ANY FUTURE STRATEGIC METAL CRISIS; UNACCEPTABLY LONG TIMES WOULD BE REQUIRED TO ACHIEVE THIS AFTER A SUPPLY SHOCK OCCURRED. ECONOMIC CONSIDERATIONS UNFORTUNATELY WILL NOT PERMIT EACH POTENTIALLY BENEFICIAL SURFACE TREATMENT TO BE EXPERIMENTALLY CONFIRMED AHEAD OF TIME. AS AN EXAMPLE, QUALIFICATION OF A NEW AIRFOIL COATING FOR AN AIRCRAFT GAS TURBINE CAN REQUIRE OVER A MILLION DOLLARS OF ENGINE TESTING AT TODAY'S FUEL PRICES.

ANY AHEAD-OF-CRISIS INVESTMENT IN SURFACE TREATMENT TECHNOLOGY SHOULD PRUDENTLY BE MADE BASED ON HIGH PROMISED PAYOFF. AT FIRST GLANCE, MANY SURFACE TREATMENTS ARE ALLURING CONSERVERS OF CRITICAL ELEMENTS; EFFORTS TO REALIZE THE PROMISED BENEFITS COULD BE EXPENSIVE DISAPPOINTMENTS. THE LOGICAL FIRST STEP IS TO REALISTICALLY EVALUATE THE BENEFITS AND RISKS OF SPECIFIC SURFACE TREATMENT TECHNOLOGIES REGARDING CRITICAL MATERIALS SUBSTITUTION. SUCH STUDIES TO DATE ARE RARE OR NON-EXISTENT. THIS IS THE PLACE TO BEGIN.



	Pounds	% Dependency	Sources
Nickel	5204	77	Canada, USSR, Australia
Chromium	1656	90 +	South Africa, USSR
Titanium	5366	100	Australia, Japan
Cobalt	910	90	Zaire, Zambia
Columbium	171	100	Brazil, Canada
Tantalum	3	96	Thailand, Canada

FIGURE 1

J24405-2
810302

RECOMMENDED APPROACHES TO ATTACK CRITICAL MATERIALS PROBLEM

- Substitution
- Conservation
- Increased domestic production
- Improved use of stockpiles
- *"Stockpiling" alternate approaches*

J25052-1
810206

FIGURE 2

STRATEGIC ELEMENTS ENHANCE ALLOY SURFACE PROPERTIES

Oxidation resistance
- Chromium, Tantalum

Hot corrosion resistance
- Chromium, Cobalt

Aqueous corrosion resistance
- Chromium

Wear resistance
- Tantalum, Tungsten, Cobalt

J25052-2
810206

FIGURE 3

TANTALUM INCREASES SUPERALLOY DURABILITY AGAINST SURFACE ATTACK

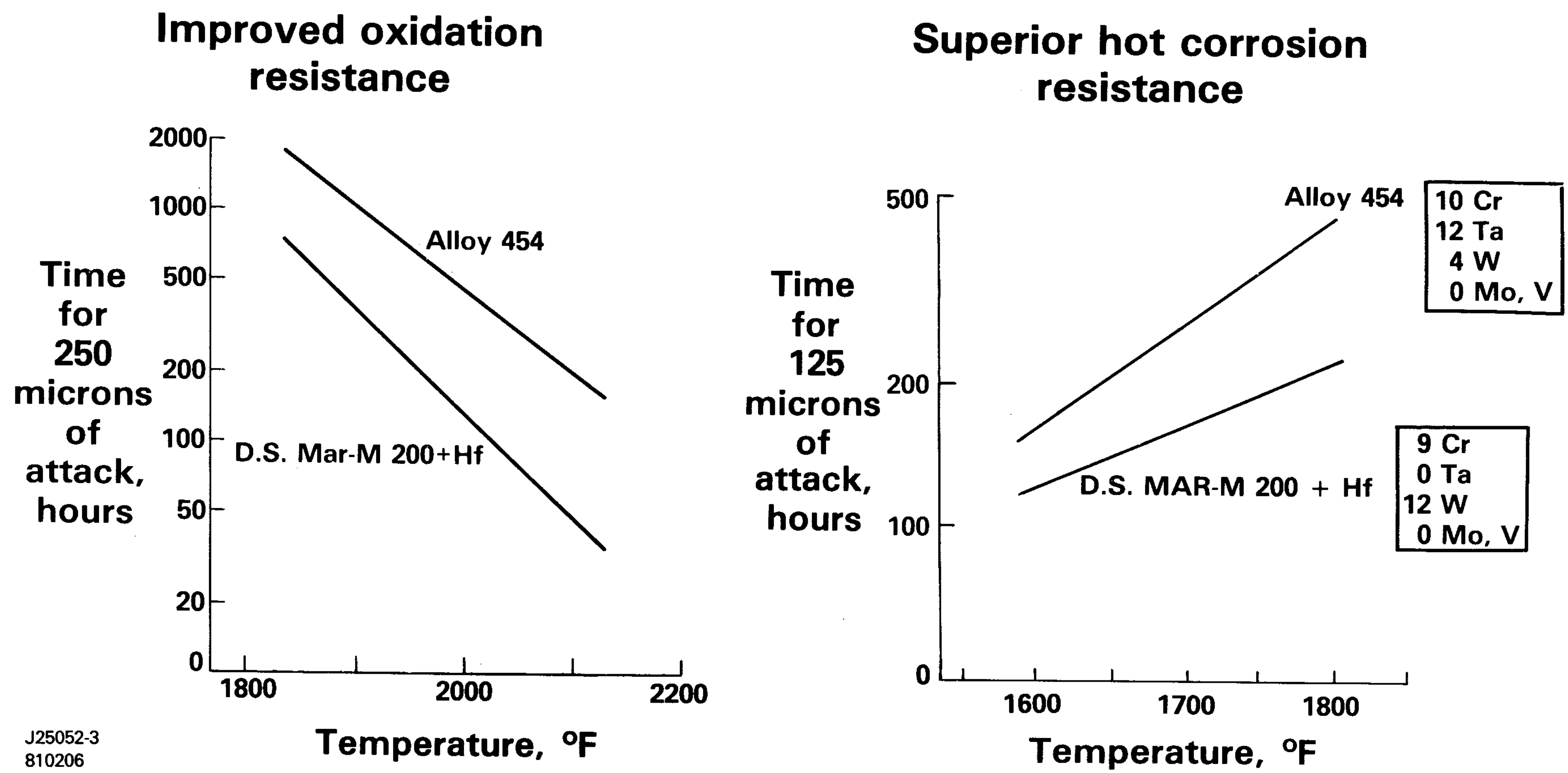


FIGURE 4

METALLURGICAL COATINGS PROVIDE AN ALTERNATE APPROACH

Approach

- Strategic-metal-lean alloys
- Strategic-metal-rich surface treatments

Benefits

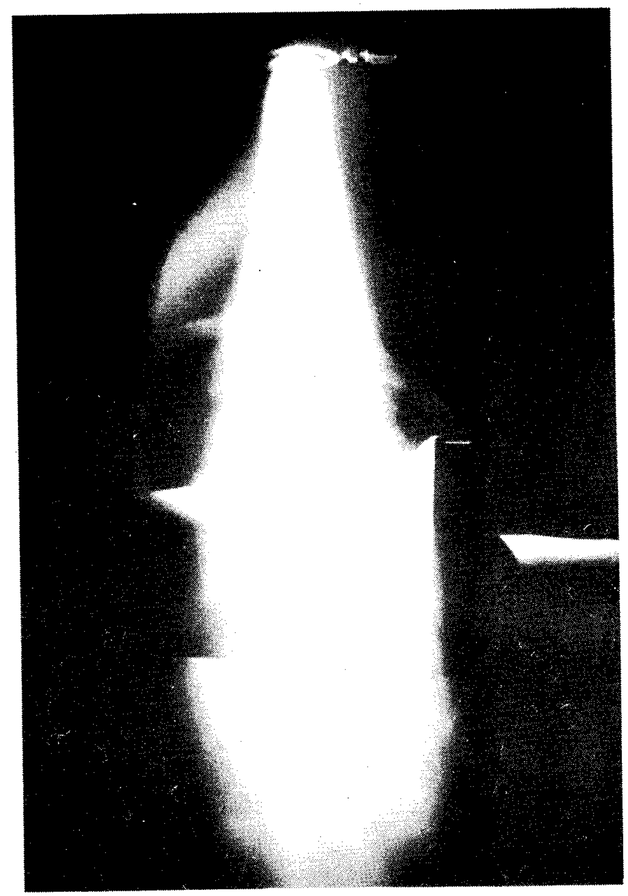
- Substantial conservation

Risks

- Removal or defeat of surface layer

Requirement

- Experience base to provide confidence

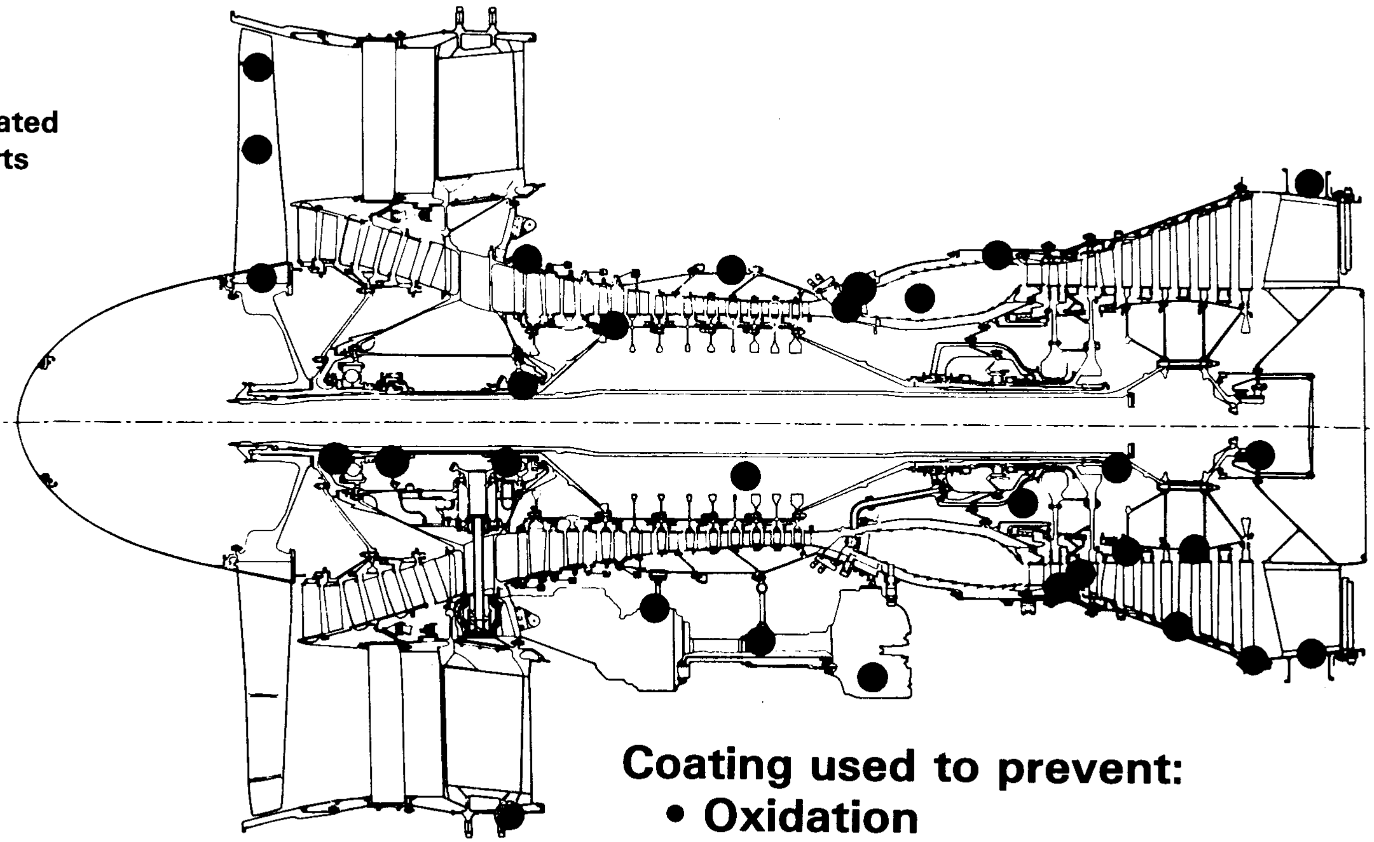


J25052-4
810206

FIGURE 5

SURFACE TREATMENTS ARE WIDELY USED IN MODERN GAS TURBINES

● Coated parts



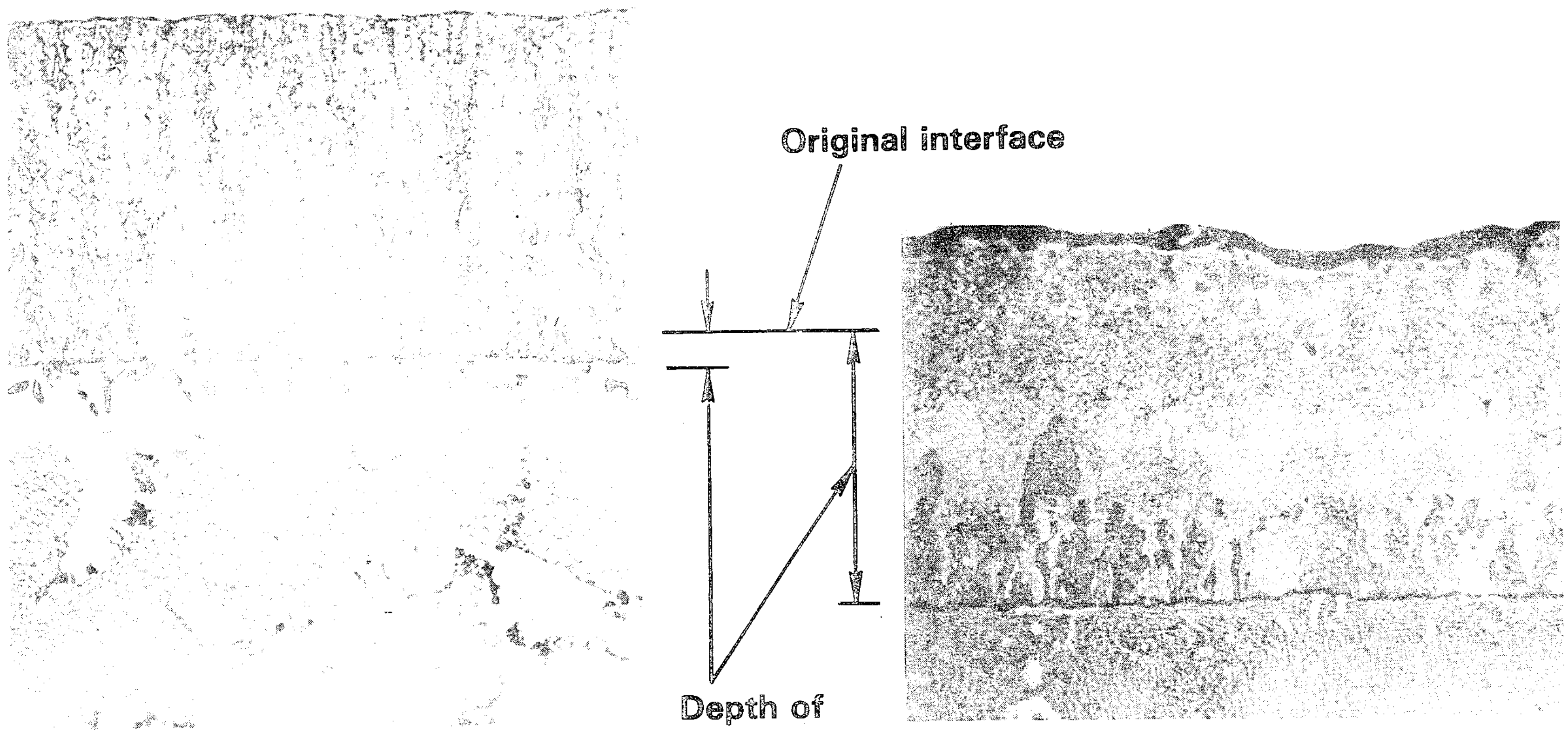
Coating used to prevent:

- Oxidation
- Corrosion
- Wear

J25052-5
810206

FIGURE 6

TURBINE AIRFOIL COATING SYSTEMS



MCrAlY overlay system
flexible
composition/structure

Diffused aluminide system
fixed
composition/structure

J25052-6
810206

FIGURE 7

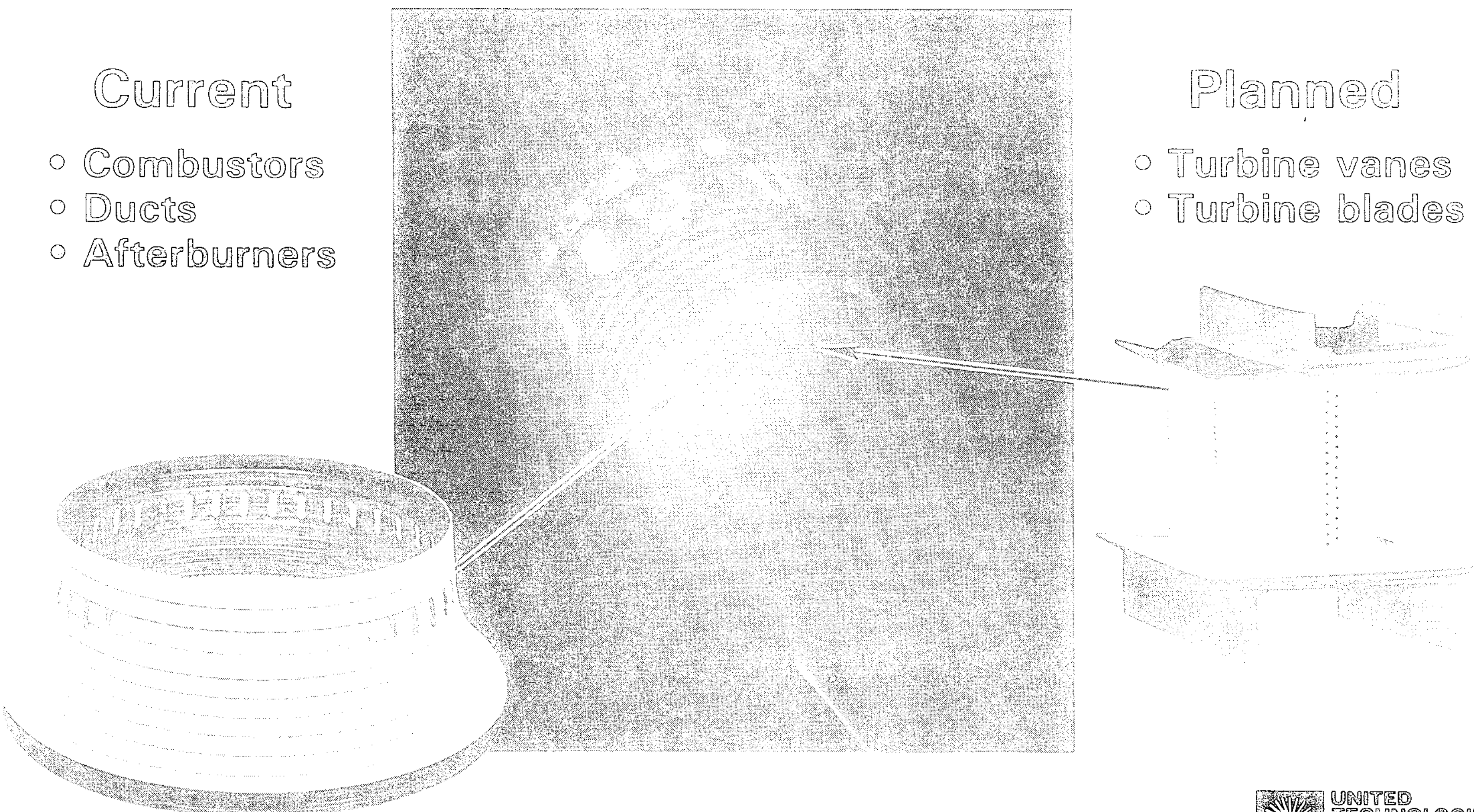
GAS TURBINE APPLICATIONS FOR THERMAL BARRIER COATINGS

Current

- Combustors
- Ducts
- Afterburners

Planned

- Turbine vanes
- Turbine blades



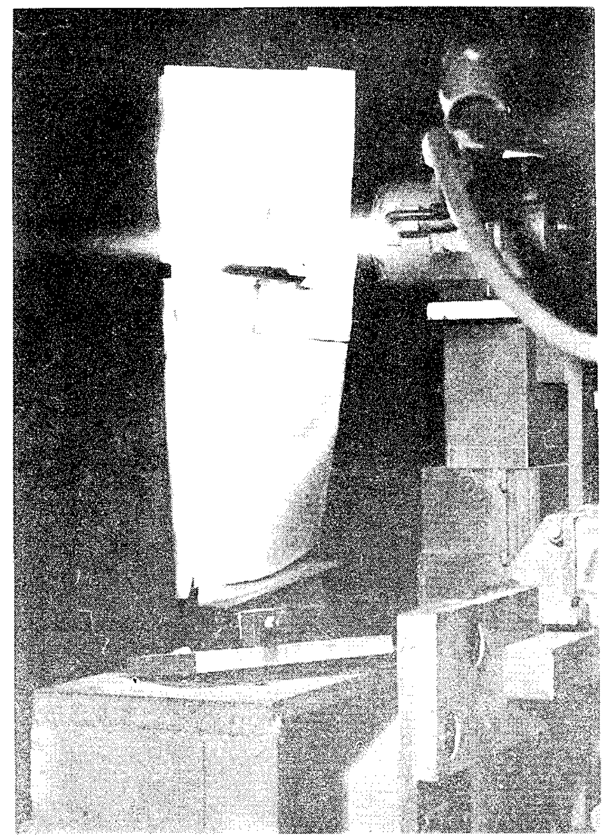
J24549-1
810603

FIGURE 8

UNITED TECHNOLOGIES
PRATT & WHITNEY AIRCRAFT

WEAR AND CORROSION RESISTANT COATINGS IN GAS TURBINES

Thermal spraying of fan blade shroud



Wear

- Thermal sprayed carbides, oxides
- Fusion welded hardface alloys
- Electroplated chromium
- Thermal sprayed copper-nickel-indium
- Miscellaneous anti-gallants

Corrosion

- Electroplated cadmium, nickel-cadmium
- Aluminum surface treatments

J25052-8
810206

FIGURE 9

COBALT CONSERVATION BY USE OF ALTERNATE COATING

Current oxidation-resistance coating

- CoCrAlY (67% cobalt)

Alternate coating

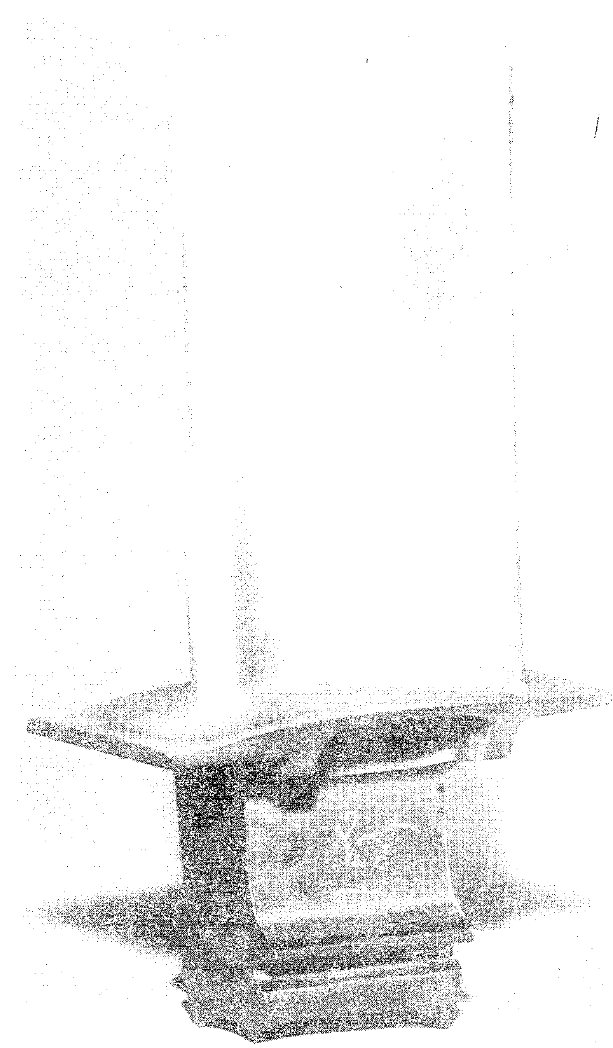
- NiCoCrAlY (23% cobalt)

Savings of cobalt

- 10,000-20,000 lbs per year

Status

- Engine tests successful
- Being evaluated in airline service

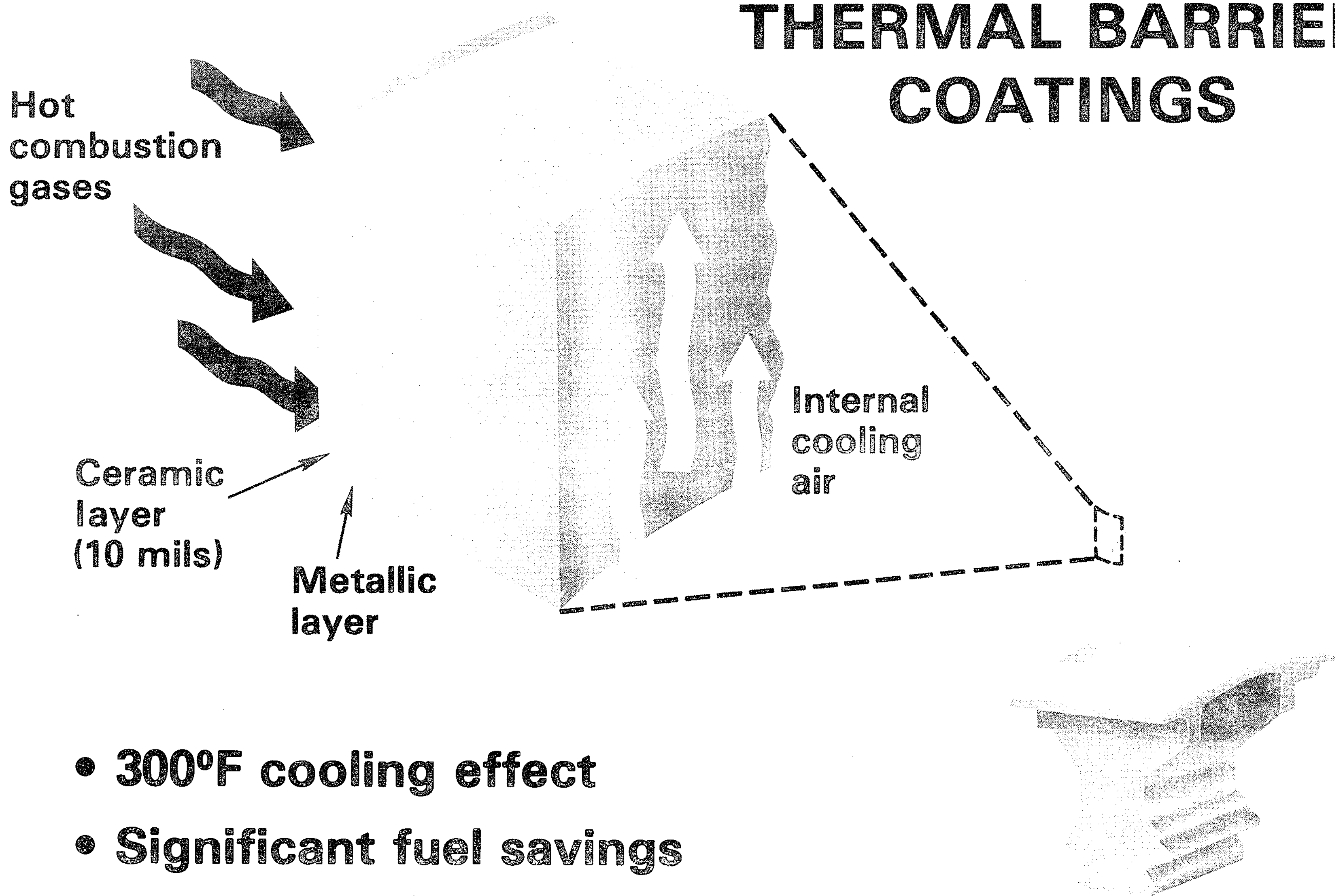


High pressure turbine airfoil

J25052-9
810206

FIGURE 10

THERMAL BARRIER COATINGS



- 300°F cooling effect
- Significant fuel savings
- Improved durability

J24549-3
810603

FIGURE 11

UNITED TECHNOLOGIES PRATT & WHITNEY AIRCRAFT

SURFACE TREATMENTS PROVIDE CORROSION PROTECTION FOR "LEAN" ALLOYS

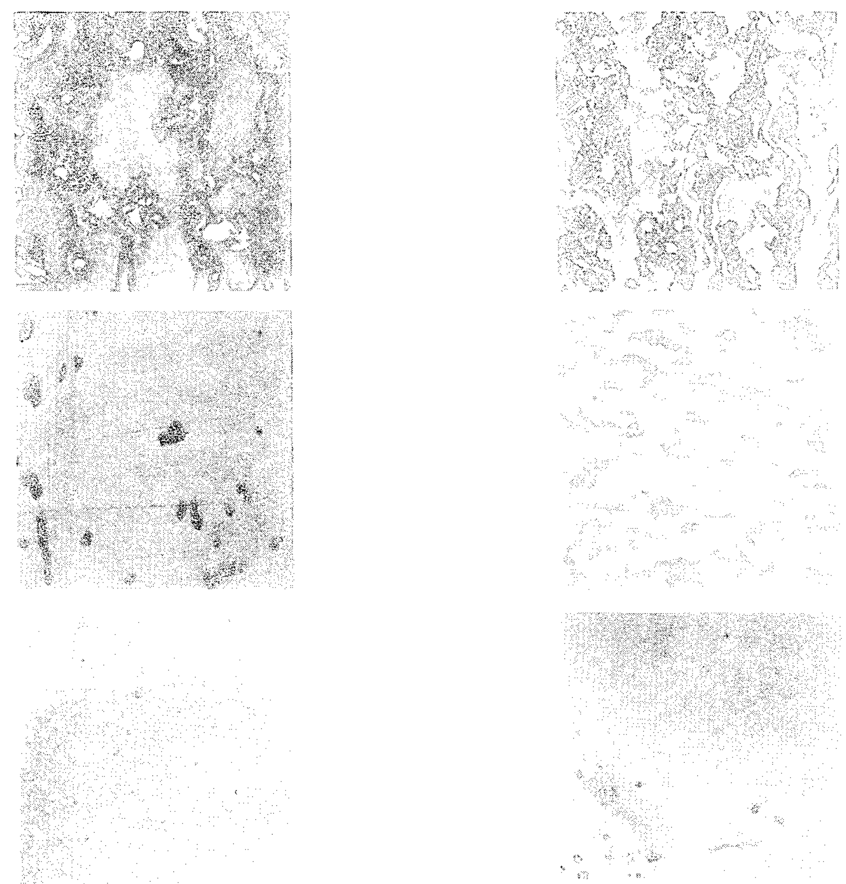
Salt spray corrosion
(6 hrs. in 5% NaCl)

Fe-12.5 Cr (AMS 5504) — Fe (AMS 5040)

Uncoated

Surface aluminized

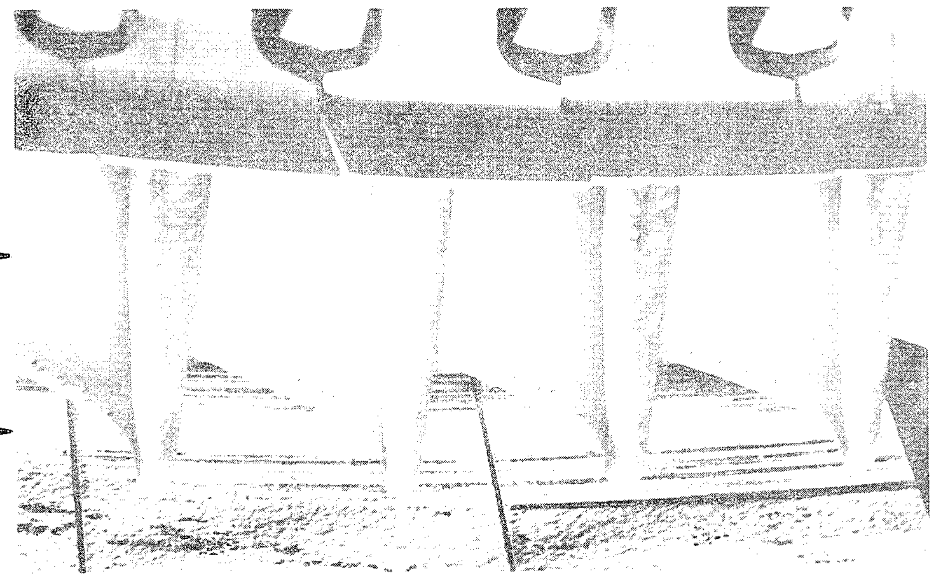
Surface chromized



J25052-11
810206

FIGURE 12

SURFACE TREATMENTS FOR TURBINE AIR SEALS



Current seal — cobalt alloy

- Oxidized cobalt has good lubricity

Alternate approach

- Nickel alloy with cobalt-base coating

Cobalt savings

- Approximately 20,000 lbs per year

J25052-12
810206

FIGURE 13

SURFACE TREATMENTS RETARD ENGINE COMPRESSOR EROSION

Erosion in aircraft engines

- Loss of material and efficiency
- Requires replacement of titanium or chromium-rich airfoils

Coatings to prevent erosion

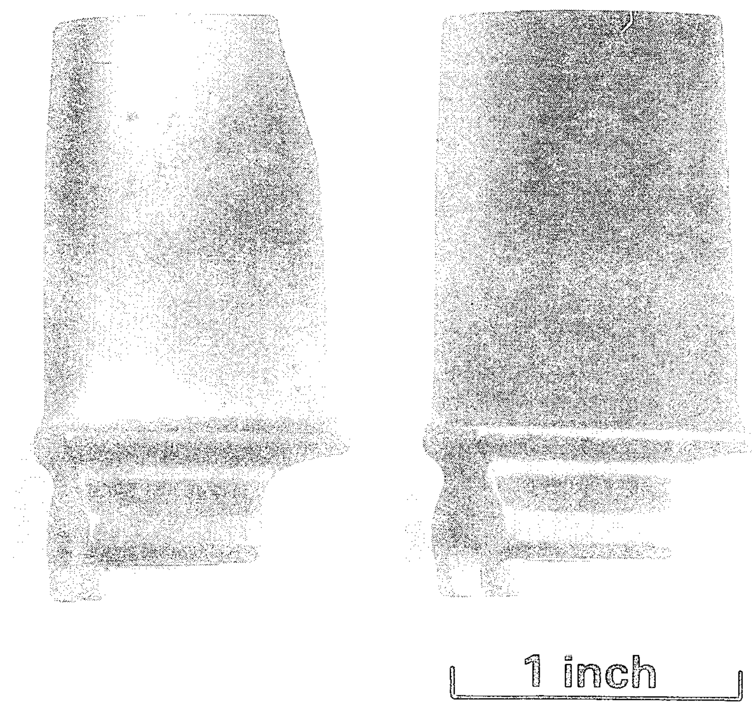
- Cobalt-Tungsten Carbide doubles life
- Development continuing under NASA program

Potential critical-metal savings

- 90,000 lbs of titanium per year
- 10,000 lbs. of chromium per year

J25052-13
810206

Laboratory erosion tests on compressor blades



Uncoated titanium

Co-WC coated titanium

FIGURE 14

- Surface treatments offer way to significant critical-metal savings
- Benefits, technical risks unclear
- Studies needed to identify the most promising applications

J25052-14
810206

FIGURE 15

POTENTIAL FOR HARD FACING APPLICATION TECHNOLOGY TO CONSERVE CRITICAL METALS

Steve J. Matthews

Cabot Corporation

POTENTIAL FOR HARD-FACING APPLICATION TECHNOLOGY TO CONSERVE CRITICAL METALS

S. J. Matthews

CABOT CORPORATION

Chairman, Subcommittee on
Hard facing and Wear
WELDING RESEARCH COUNCIL

Presented June 16, 1981 at the Workshop on
Conservation and Substitution Technology for
Critical Materials, Vanderbilt University

Session IIIB - "Technological Opportunities for Conservation
of Critical Metals Utilizing Metallurgical Coating Systems

INTRODUCTION

The purpose of this presentation is to describe the overall concept of hard facing as an effective method of wear control, and to discuss the application of this technology to conserve critical materials. The basic theme of this presentation is that cheaper, less strategic base materials can be made serviceable in harsh wear environments, provided the surfaces are protected by application of a wear resistant weld overlay material.

DEFINITION OF HARD FACING

Hard facing is a term describing the application of a hard material to the surface of a component by welding (or by an allied welding process) for the main purpose of reducing wear. Wear can be defined as the loss of material by abrasion, impact, erosion, cavitation, galling, or metal-to-metal adhesion. It should be recognized that wear is a surface phenomenon. As the surface of a component wears away, it usually becomes less efficient or even disabled, usually because of loss of dimensional clearance or configuration. The annual cost of "wear" to the United States economy is estimated to be about $60 billion dollars, rivaling another well known destructive nemesis: corrosion.

There is a wide variety of tribologically different types of wear, each with their own mechanisms. "Tribology" is a term coined to describe the science of friction, wear and lubrication. The mechanical engineering community has addressed the subject of wear for several years in this country, attacking the problem with lubrication technology and improved mechanical designs. However, it should be recognized that wear is dramatically compounded in harsh environments characterized by corrosion, high temperature, high loads, and severe abrasion where lubrication technology simply won't work. It would be meaningless for instance to "oil" the edge of a plow share for agricultural tillage. Protection of a surface with a hard, wear resistant material is therefore the only meaningful alternative, if wear prevention is to be pursued in unlubricated applications.

HARD FACING PROCESSES AND DEPOSITION TECHNIQUES

Hard facing is a particular form of weld overlay surfacing. A great deal of the welding and joining technology developed in the United States over the last 30 years is applicable to hard facing, especially in terms of the processes and equipment used to deposit hard-facing alloys onto a surface.

Table 1 lists the various welding processes commonly used for hard facing, along with characteristic percent dilution and deposition rate associated with each process. The extent of base material dilution into the hard-facing overlay is an important feature to minimize since excessive dilution will compromise the metallurgical effectiveness of the hard-facing material. This invariably results in lower hardness and generally less effective wear resistance. It would be advantageous on the other hand for deposition rate to

be high for economic reasons (i.e., less time to complete the job). There has been a distinct trend in this country over the past 5 years towards increased automation and mechanization, especially using the gas tungsten arc and plasma transferred arc hardfacing processes. Mechanization serves not only to increase productivity, but also eliminates the variable of manual fatigue, thereby immproving product quality, consistency and reliability..

Hard-facing consumables to "feed" the various hard-facing processes have historically been manufactured in the form of bare cast rod. The increased trend towards automation, however, has prompted increased production of other consumable forms, namely, continuous cast rod, continuous wires, and also powders in the case of the plasma transferred arc process. Hard-facing alloys are intrinsically hard and therefore make manufacturing by traditional casting and wroughting techniques relatively difficult. The atomization of molten metal to produce powders overcomes these difficulties, thereby suggesting even greater advantages of the plasma transferred arc process as a highly efficient hard facing system.

HARD FACING ALLOYS

Because wear is a complex phenomenom compounded by a wide variety of different service environments, there is no single hard facing alloy that will universally resist all types of wear. Hence, the existence of literally hundreds of different hard-facing alloys on the market today. Most hard-facing alloys can be classified into one of the following general classifications:

Cobalt-base alloys
Nickel-base alloys
Iron-base alloys
Tungsten carbide composite alloys

Table 2 identifies the nominal composition of representative alloys for each classification. It is also ironic to note that almost all hard-facing alloys, especially the cobalt family, rely heavily on strategic materials for their chemical make-up. A discussion of each family of materials can be given as follows:

Cobalt-base Alloys

Cobalt base alloys come the closest to being "universal" hard-facing materials since they have been industrially proven to resist not only abrasion and metal-to-metal wear, but are also resistant to high temperature and/or corrosion environments. A good example is in the valve industry where both fluid flow and automotive diesel valve seats are commonly hard faced with cobalt alloys.

Metallurgically, these alloys contain three very strategic elements: cobalt, chromium and tungsten. Liberal amounts of carbon are added to form a chromium carbide network to resist abrasive wear. The cobalt matrix tends to resist the metal-to-metal wear. The chromium in solid solution with the matrix resists corrosion. The tungsten also in solid solution serves to increase resistance to deformation at elevated temperatures (i.e., hot hardness).

As a result of the 1978 "cobalt crisis, considerable efforts have been expended on the part of hard-facing producers and users alike to find a cobalt base alloy substitute. Using principles of physical metallurgy proven effective in the design of high temperature and corrosion resistant alloys, hard-facing alloy development programs have also been conducted. A number of alloys based upon an iron-plus-nickel substitution for cobalt have been identified, and some of these alloys have been accepted in industry for certain applications. Based on laboratory data, these "cobalt-substitute alloys" have been found to exhibit equivalent wear resistance (with the exception of galling) compared with cobalt base alloys. The only practical disadvantage has been reduced weldability characteristics (i.e., more prone to porosity and/or cracking).

Nickel-base Alloys

Most of the traditional nickel base alloys are based upon the nickel-chromium-silicon-boron system, and, microstructurally, are characterized by large volume fractions of hard boride phases. These alloys offer excellent abrasion resistance, coupled with relatively good corrosion resistance. However, they generally suffer greater loss of hot hardness and rarely compete with cobalt base alloys at service temperatures greater than 1000°F. Galling resistance, as a rule, is also inferior. As a family of alloys they also are more prone to cracking during hard facing deposition in comparison to cobalt base alloys.

Iron-base Alloys

This family of alloys is often used in metal-to-metal wear environments <u>not</u> compounded by corrosion or high temperature. Compositionally, they contain relatively small amounts of chromium and tungsten to produce low or medium alloy steel type of alloys. However, there is another family of higher alloyed iron-based hard facing materials containing up to 30% chromium and 4% carbon. These alloys are designed to resist earth and rock abrasion by virture of large volume fraction of chromium carbides present in the microstructure. Typical applications include coal and rock crushing equipment and farm implement tools.

Tungsten Carbide Composite Alloys

These are referred to as composite alloys because the deposition method usually involves introducing crushed tungsten carbide particles into a molten deposit, and allowing the composite overlay to solidify. This results in a tough matrix (usually steel) plus a coarse dispersion of hard tungsten carbide particles. Since tungsten carbide is one of the hardest materials known to man, the alloys are used in severe abrasion conditions, such as rock drilling bits and other cutting or chipping type applications. Tungsten carbide readily oxidizes and, therefore, cannot be used at elevated temperatures.

HARD FACING PHILOSOPHY

The use of hard facing today can presently be found in a wide variety of industries, some of which are listed in Table 3. Hard facing can be applied either at the time of original equipment manufacture (OEM) (for example , valve seats, screw flights, turbine hardware) or as a maintenance technique to extend the life of existing equipment and components (i.e., tractor undercarriage parts, bucket teeth, mine car wheels, etc.).

Often, it is in the OEM applications that one finds the deposition of a cobalt base alloy, for instance, onto a highly alloyed material such as stainless steel. From a strategic metal viewpoint, one might argue the virtue of using even more strategic metals (i.e., cobalt) on top of something that is already strategic (i.e., chromium in the stainless steel base material). The counter argument is obvious. The wear resistance of the hard-facing alloy is superior to the base material, hence one is attempting to preserve the valuable metals within the original component by extending the service life of the equipment indefinitely. The same philosophy is present when one buys home or auto insurance (you pay a little more to protect your original investment).

In contrast to OEM, the "maintenance" type of hard facing is often characterized by the application of a high chromium iron base hard facing alloy to a mild steel base material. Proponents of conserving strategic metals might argue against hard facing, saying it would be advantageous to simply replace the "cheap and dirty" worn out steel with new (non-strategic) steel. The fact of the matter is that Americans can no longer afford to live in a "throw away" society. Conservation of all materials via wear protection means not only conservation of raw materials, but also conservation of energy. By extending the life of even a common mild steel part, via hard facing, we have "saved" the energy that would have to be expended to replace that part in total (i.e., energy expended to mine iron ore, transport, reduce to metal, melt, cast, hot roll, cut, shape, etc.)

Perhaps the greatest opportunity for the application of hard-facing technology to conserve critical materials is a "design-for-maintenance" philosophy. Rather than attempting to design the entire body of a component out of a material highly alloyed in strategic materials, it would be wiser to construct the part using less critical materials and then hard face the surface with suitable alloy to resist wear. This approach even offers a little known fringe benefit for the welding engineer. For metallurgical reasons, it is easier to hard face mild steel than it is to hard face alloy steels and especially martensitic stainless or precipitation hardened steels. As a rule, mild steels can be hard faced with less preheat and no post weld heat treatment, thereby offering an even further advantage of reduced energy consumption.

HARD-FACING R&D TRENDS

Considerable research and development is still needed if hard facing is to be fully exploited as a method of conserving strategic materials. A review of hard-facing R&D activity over the decade 1960 to 1970 reveals little or no interest expressed by the engineering community on the subject of hard facing. However, during the following decade, 1970 to 1980, the engineering community, especially metallurgical and welding orientated technologies, began to take a keen look at hard facing as an effective method of wear control. This interest, of course, was brought about by spiraling material costs, material shortages, and long delivery times, characteristic of American industry during the 70's. Prior to this era, the "black art" of hard facing had been treated rather unscientifically. Hard-facing materials and processes had been used on a trial and error basis with little attempt to understand basic engineering principles.

In 1975, the Welding Research Council established a new high alloy subcommittee devoted specifically to the subject of hard facing and wear. Interest and activity in this subcommittee has grown steadily over the past six years. Subcommittee membership enrollment alone has increased at a rate of 20% per annum.

In 1979, the first Engineering Foundation Conference ever held in this country devoted to the subject of "hard facing" was held at Asilomar, California. The conference involved five days of meetings and discussions centered on hard-facing metallurgy, wear test methods, processes and applications. Presentations highlighted a number of well executed studies already initiated by private enterprise to explore the technology of hard facing, while many other presentations cited the need for further work.

In 1982, a follow-up Engineering Foundation Conference will be held in Henniker, New Hampshire. This conference will be aimed at "advances" in hard facing technology, namely: development, process mechanization, property and wear characterizations, and hard facing applications and economics.

A further prediction for R&D activity in this country over the next decade, 1980 to 1990, should be characterized by continued interest in hard facing, not only by the "engineering community", but also by private industry and university researchers, hopefully in conjunction with government support. Currently, the University of Notre Dame and the Colorado School of Mines are the only two institutions of higher learning in this country actively involved in some form of hard-facing research.

The continued high level of interest in hard facing during the 80's should logically be prompted by the national goals of increased productivity and less dependence on foreign resources, both energy and minerals. There is a great potential for hard-facing technology to meet all of these goals.

TABLE 1

WELDING PROCESSES USED FOR HARD-FACING OVERLAY

Process	Typical Base Metal Dilution	Typical Deposition Rates (lbs/hr)
Oxyacetylene	1 - 5%	2 - 3
Manual Gas Tungsten Arc	15 - 25%	2 - 3
Shielded Metal Arc	20 - 30%	3 - 5
Flux Cored Arc (open arc)	15 - 25%	8 - 15
Submerged Arc	30 - 50%	10 - 20
Plasma Transferred Arc	5 - 15%	5 - 12

TABLE 2

NOMINAL CHEMICAL COMPOSITIONS OF REPRESENTATIVE HARD-FACING ALLOYS

General Classification	Typical Composition of Representative Alloy						
	Co	Ni	Fe	Cr	W	C	Other
Cobalt-base	65	1	1	28	4	1.0	-
"Cobalt Substitute" Alloy	12	23	29	26	4	1.1	3 Mo
Traditional nickel-base	0	72	4	15	0	0.8	4.0 Si 3.5 B
Iron-base (low carbon)	0	0	92	5.5	0	0.7	-
Iron-base (high carbon)	0	0	64	30	0	3.5	1 Mo
Tungsten carbide composites	0	0	40	0	54	6.0	-

TABLE 3

SOME INDUSTRIES WHICH USE HARD FACING AS A METHOD OF WEAR CONTROL

Industry	Typical Application
Agriculture	Plow shares
Brick/cement	Chutes and conveyors
Chemical	Plastic extrusion screws
Construction	Bulldozer parts
Food Product	Mixer Paddles
Foundry	Sand mixers/slingers
Glass Bottle	Mold edges and faces
Metal Forming	Forging hammers
Mining/quarrying	Rock crushers
Petroleum	Tool joints
Power Utility	Hammer mill (coal) hammers
Steel	Blast Furnace bells
Pulp and Paper	Chipper knives
Valve	Valve seat and trim

POTENTIAL FOR CLADDINGS TO CONSERVE CRITICAL METALS

James M. Glazebrook
Lukens Steel Co.

POTENTIAL FOR CLADDINGS TO CONSERVE CRITICAL METALS

James M. Glazebrook
Manager, Head and Clad Sales
Lukens Steel Company

FOR PRESENTATION AT WORKSHOP ON
CONSERVATION AND SUBSTITUTION TECHNOLOGY
FOR CRITICAL MATERIALS

VANDERBILT UNIVERSITY
NASHVILLE, TENNESSEE
JUNE 16, 1981

POTENTIAL FOR CLADDINGS TO CONSERVE CRITICAL METALS

COMBINING TWO METALS BY WORKING THEM TOGETHER IN A FORGE TO PRODUCE AN OBJECT MORE USEFUL OR ARTISTIC THAN EITHER METAL ALONE IS AS OLD AS METALWORKING HISTORY.

AND TODAY, THE USE OF BI-METAL COMBINATIONS ARE AS COMMON AS THE COINS RATTLING IN OUR POCKETS.

BACK IN THE 1960'S, FACED WITH POTENTIAL SHORTAGES AND CERTAIN ESCALATING PRICES FOR SILVER, THE U.S. MINT VENTURED INTO THE CLAD METAL BUSINESS. ALMOST TWENTY YEARS LATER WE FIND THAT EVERY COIN ABOVE A NICKEL IS A CUPRO-NICKEL -- COPPER COMPOSITE. THE RESULT, AND THE HUNT BROTHERS NOT-WITHSTANDING, IS A SUBSTANTIAL SAVINGS OF SILVER FOR THE GOVERNMENT.

TODAY, COMPOSITE METALS ARE PRODUCED IN A VARIETY OF COMBINATIONS AND FORMS. THESE RANGE FROM APPLICATIONS AS COMMON AS COINS TO EXOTIC, ONE-OF-A-KIND ELECTRONIC CONNECTORS USED ON THE SPACE SHUTTLE.

COMPOSITE METALS NOW ARE PRODUCED IN A VARIETY OF COMBINATIONS AND FORMS WHICH ARE ESSENTIAL TO MODERN LIFE. INCLUDED ARE RIBBON, FOIL, TUBING, PIPE, WIRE, INLAYS, SHEET, STRIP, AND PLATE -- USED IN THE ELECTRICAL, ELECTRONIC, SEMI CONDUCTOR INDUSTRIES; IN MEDICINE; IN COOKING UTENSILS; IN JEWELRY AND COINS; AND IN OUR PROCESS INDUSTRIES. INTEGRALLY BONDED COMPOSITE SHEET, STRIP, AND PLATE ARE BEING PRODUCED BY COLD ROLLING, HOT ROLLING, PRESSING, BRAZING, WELDING, ELECTROPLATING, SINTERING, OR COMBINATIONS OF THESE METHODS.

HOT ROLLED STEEL PLATE ACCOUNTS FOR THE GREATEST TONNAGE OF CLAD METAL BEING MADE AND PROVIDES THE LARGEST OPPORTUNITY FOR CONSERVATION OF SCARCE METALS. CLAD STEEL PLATE MAY BE DEFINED AS A COMPOSITE IN WHICH THE TWO OR MORE METALS ARE 100 PERCENT METALLURGICALLY BONDED. THIS DEFINITION EXCLUDES APPLICATION OF SHEET LININGS BY INTERMITTENT FUSION OR SPOT WELDS; THOUGH, IN THE PAST, RESISTANCE SPOT WELDED COMPOSITE PLATES MADE BY ONE LARGE PRESSURE VESSEL MANUFACTURER HAD NEARLY A 100 PERCENT BOND.

CLADDING OF STEEL PLATE HAD ITS BEGINNING IN THE LATE 1920'S WITH THE DEMAND OF THE CHEMICAL INDUSTRY FOR LARGE NICKEL VESSELS TO CARRY CAUSTIC. LUKENS DEVELOPED THE SANDWICH ROLLING METHOD, AND IN 1930 SOLD THE FIRST NICKEL CLAD STEEL PLATE. THE PETROLEUM INDUSTRY AT ABOUT THE SAME PERIOD WAS REALIZING THE NEED FOR STAINLESS STEEL FOR LARGE PROCESS VESSELS. IN THE MID THIRTIES, ATTEMPTS WERE MADE TO BOND STAINLESS AND CARBON STEEL PLATE BY ROLLING THEM WITH AN INTERLAYER OF INGOT IRON. THIS METHOD DID NOT PRODUCE A SATISFACTORY BOND AND WAS SUCCEEDED BY THE PLURAMELT PROCESS IN WHICH STAINLESS STEEL WAS FUSION WELDED VERTICALLY AGAINST A STEEL SLAB, THEN HOT ROLLED TO PLATE. PLURAMELT PROVED TO BE UNECONOMICAL AND WAS SUPPLANTED IN THE EARLY 1940'S BY A METHOD IN WHICH IRON WAS ELECTRO-PLATED ON THE STAINLESS. AN ASSEMBLY WAS THEN HOT ROLLED TO PLATE AS LUKENS DID WITH NICKEL CLAD. THIS METHOD PRODUCED A STRONG BOND BUT ALSO ALLOWED A LOT OF CARBON TO DIFFUSE IN THICK, HEAT TREATED PLATE. IN THE MID FORTIES, LUKENS BEGAN TO PRODUCE STAINLESS CLAD STEEL PLATE BY ELECTRO-PLATING WITH NICKEL. THIS METHOD NOW IS USED BY MANY OTHER STEEL MILLS AROUND THE WORLD.

THE USE OF ELECTROPLATED NICKEL MAKES POSSIBLE A SOLID PHASE WELD DURING THE HEATING AND ROLLING OF A WELDED "SANDWICH" BECAUSE IT AVOIDS OXIDATION OF HIGH CHROMIUM ALLOYS WITHIN THE WELDED PACK. IT HAS THE FURTHER ADVANTAGE OF RETARDING DIFFUSION OF CARBON FROM THE STEEL INTO THE STAINLESS STEEL AFTER THE SURFACES HAVE BEEN WELDED TOGETHER. ROLLING WITH AN INTERLAYER OF ELECTROPLATED NICKEL IS PRESENTLY USED TO MAKE INTEGRAL BI-METALLIC PLATES WITH CLADDING METALS AS DIVERSE AS PURE COPPER AND SUCH NICKEL BASE CHROMIUM MOLYBDENUM ALLOYS AS INCONEL 625. THESE TWO MATERIALS REPRESENT EXTREMES IN HARDNESS AT STEEL ROLLING TEMPERATURES. THE COMPATIBILITY OF HOT WORKING CHARACTERISTICS OF STEEL AND THE CLADDING METAL ARE THE ONE FACTOR GOVERNING THE FEASIBILITY OF ROLL CLADDING. ALUMINUM CAN BE, AND HAS BEEN, ROLL CLAD TO CARBON STEEL; BUT THE PROCEDURES REQUIRED TO DO IT SUCCESSFULLY ARE NOT ECONOMICAL IN THE STEEL MILL. SUCCESSFUL HOT ROLL BONDING OF COMPOSITES ALSO DEPEND UPON THE PROPERTIES OF THE ALLOYS FORMED BY DIFFUSION AT THE INTERFACE. TITANIUM FORMS BRITTLE INTERMETALLIC ALLOYS WITH NICKEL OR IRON AND IS NOT EASILY CLAD TO CARBON STEEL IN THE MILL.

TWO OTHER METHODS FOR MANUFACTURING LARGE INTEGRALLY CLAD STEEL VESSELS ARE IN WIDE USE TODAY AND EACH HAS ITS TECHNOLOGICAL AND ECONOMIC ADVANTAGES.

ONE OF THESE METHODS OF CLADDING IS FUSION WELD OVERLAY.

A GREAT MANY FABRICATORS HAVE THE EQUIPMENT AND KNOW-HOW FOR PRODUCING ECONOMICAL OVERLAYS WHICH ARE PHYSICALLY SOUND AND CHEMICALLY AND METALLURGICALLY EQUAL TO WROUGHT ALLOYS IN SERVICEABILITY. PREDOMINANTLY, THE METALS APPLIED TO CARBON STEEL BY WELD OVERLAYING ARE THE AUSTENITIC STAINLESS ALLOYS; BUT WELD CLADDING OF CARBON STEEL CAN BE PERFORMED WITH ANY METAL WHICH CAN BE DEPOSITED BY ARC WELDING -- COPPER, COPPER BASE ALLOYS, AND NICKEL BASE ALLOYS.

THE ECONOMY OF OVERLAY CLADDING -- AS AGAINST PURCHASE OF MILL CLAD OR EXPLOSION CLAD PLATE -- DEPENDS UPON THE EFFICIENCY WITH WHICH THE FABRICATOR IS ABLE TO DEPOSIT A METALLURGICALLY SUITABLE OVERLAY. WHAT HE MUST DO IS TO ACHIEVE A HIGH DEPOSITION RATE WHILE MINIMIZING THE AMOUNT OF BASE STEEL MELTED INTO THE CLADDING. FABRICATORS USE VARIOUS MEANS OF DOING THIS. MOST LARGE-SCALE OVERLAYING IS DONE WITH THE SUBMERGED ARC PROCESS. IN THE CASE OF STAINLESS STEEL, FLUXES WITH CR, NI, AND MO REINFORCEMENT ARE AVAILABLE TO COMPENSATE FOR IRON PICKUP; BUT EVEN SO, ARC ENERGY MUST BE CONTROLLED TO LIMIT CARBON CONTENT IN THE CLADDING. SO THE FABRICATOR'S BASIC PROBLEM IS TO ACHIEVE HIGH DEPOSITION RATE WITH LOW PENETRATION. VARIOUS TECHNIQUES TO DO THIS ARE AVAILABLE. A COLD WIRE CAN BE FED INTO THE ARC, SERIES ARC CONNECTION, OR STRAIGHT POLARITY CAN BE USED. MOSTLY WHAT IS DONE IS TO USE LOW ARC ENERGY INPUTS AND TO INCREASE THE NUMBER OF ARCS BY USING THREE OR EVEN SIX WIRE ELECTRODES SIMULTANEOUSLY. ANOTHER SYSTEM IS TO USE A METAL STRIP INSTEAD OF WIRE ELECTRODES. THEN THE ARC OF REDUCED INTENSITY TRAVELS ALONG THE STRIP KEEPING PENETRATION DOWN BUT MAINTAINING HIGH DEPOSITION RATE. COMPOSITE WIRES ARE COMMONLY USED FOR WELD CLADDING. THESE ARE TUBES WHICH CONTAIN THE ALLOYS DESIRED IN THE OVERLAY. SUCH ELECTRODES OFFER FLEXIBILITY IN ALLOY SELECTION AND ALSO GIVE AN ARC OF REDUCED PENETRATING FORCE. COMPOSITE ELECTRODES CONTAINING FLUX ARE AVAILABLE FOR OPEN-ARC WELDING.

IN 1964 A THIRD METHOD OF PRODUCING LARGE CLAD PLATES BECAME AVAILABLE TO INDUSTRY. AFTER MANY YEARS OF RESEARCH ON PHENOMENOLOGICAL THEORY AND DEVELOPMENT OF PRACTICE, DUPONT OPENED A PLANT FOR CLADDING METALS BY THE USE OF A CONTROLLED EXPLOSION. ESSENTIALLY, TWO OR MORE METAL SURFACES ARE FIXED PARALLEL AND SLIGHTLY APART. AN EXPLOSIVE CHARGE CAUSES A PROGRESSIVE ANGULAR COLLISION BETWEEN THE CLADDING METAL AND THE SUBSTRATE. THE FORCE OF THE COLLISION PRODUCES A JET OF METAL WHICH SWEEPS AWAY SURFACE

CONTAMINANTS AND CAUSES A SOLID PHASE WELD TO BE MADE UNDER THE DETONATION FRONT. THE EXPLOSION WELDED INTERFACE IS A PATTERN OF REGULAR WAVES CREATED BY PLASTIC FLOW. A SMALL AMOUNT OF MELTING MAY OCCUR; IN WHICH CASE THE MELTED METAL IS ENCASED BY DUCTILE MATERIAL IN THE TROUGH OF THE WAVES.

BECAUSE EXPLOSION BONDING IS DONE COLD AND IS ESSENTIALLY DIFFUSIONLESS, THE PROCESS IS ADMIRABLY SUITED TO JOINING METALS WHICH ARE REACTIVE AND WHICH FORM BRITTLE INTERMETALLICS SUCH AS TITANIUM STEEL, ALUMINUM/STEEL. IT IS ALSO CAPABLE OF BONDING MORE THAN TWO DIFFERENT METALS SIMULTANEOUSLY AND OF CLADDING METALS WHICH ARE VASTLY DIFFERENT IN MELTING POINTS AND MECHANICAL CHARACTERISTICS SUCH AS TANTALUM/COPPER/STEEL. AS IS TRUE OF THE OTHER CLADDING PROCESSES, THERE ARE PREREQUISITES FOR SUCCESSFUL EXPLOSION BONDING. A CERTAIN AMOUNT OF DUCTILITY IS REQUIRED OF THE CLADDING METAL AND THE SUBSTRATE MUST POSSESS ENOUGH FRACTURE TOUGHNESS TO RESIST THE IMPACT LOADING OF THE EXPLOSION. METALS OVER 100 KSI YIELD STRENGTH ARE NOT EASILY CLAD BY THE EXPLOSION PROCESS.

THE CAPACITY FOR INCREASE IN PRODUCTION OF CLAD BY ALL THREE METHODS IS VERY LARGE AS IS THE POTENTIAL FOR DEVELOPMENT OF CLAD COMBINATIONS AND METHODS NOT NOW IN USE.

THERE ARE SOME ENGINEERING APPLICATIONS FOR WHICH COMPOSITE PLATE AND ONLY COMPOSITE PLATE IS SUITABLE; BUT IN GENERAL, CLAD PLATE IS USED WHERE IT IS AN ECONOMICAL SUBSTITUTE FOR THE HOMOGENEOUS METAL REQUIRED FOR THE INTENDED USE. THE RATIO OF FINISHED PRICE OF A CLAD STEEL VESSEL TO THE PRICE OF THE HOMOGENEOUS ALLOY VESSEL IS GREATER THAN THE RATIO OF CLADDING. FOR THIS REASON, CLAD STEEL IS USED ONLY WHERE CORROSION RATES ARE LOW. THE MORE EXPENSIVE THE ALLOY, HOWEVER, THE MORE FAVORABLE WILL BE THE PRICE OF THE CLAD PLATE. OF COURSE, THE PRICE OF A COMPLETED VESSEL

DEPENDS UPON FABRICATION AS WELL AS CLAD COSTS. THIN CLAD PLATES ARE LIKELY TO COST SOMEWHAT MORE TO FABRICATE THAN WOULD AN ALL-ALLOY PLATE; BUT AS THICKNESS INCREASES, SAVING OF ALLOY WELD METAL INCREASES. AGAIN, THE MORE EXPENSIVE THE ALLOY, THE GREATER THE SAVING.

IT IS SAFE TO SAY THAT THE EXTENT OF CURRENT USAGE OF CLAD PLATE AS A SUBSTITUTE FOR ALL-ALLOY PLATE IS DICTATED PRIMARILY BY THE RELATIVE COSTS OF THE TWO PRODUCTS RATHER THAN BY TECHNOLOGICAL CONSIDERATIONS. TO PUT IT ANOTHER WAY, A LOT OF CHROMIUM WHICH WILL NEVER SEE A CORROSIVE ENVIRONMENT IS BEING USED TO PROVIDE SUPPORT IN TANKS AND TO RETAIN PRESSURE IN VESSELS.

PERHAPS EVEN MORE IMPORTANTLY, WHEN MAKING LONG-RANGE PLANS THERE WILL BE OTHER FACTORS WHICH BEAR CONSIDERATION. ALL OF US WHO STRUGGLED THROUGH THE PAST TWO OIL CRISES ARE AWARE OF THE CONSEQUENCES OF UNSTABLE SUPPLY SOURCES. WE ALL SAW SHORT RUN PURCHASE CRITERIA SUCH AS PRICE BEING DISCARDED THE MOMENT AVAILABILITY BECAME THREATENED. IN THE LONG RUN, CAN'T IT BE SAID THAT WE ARE FACING THE SAME TYPE OF PROBLEM IN STRATEGIC MATERIALS?

AND THEN WOULDN'T IT FOLLOW THAT PRAGMATIC CONSERVATION PRACTICED BEFORE THE FACT COULD HELP FORESTALL OR BLUNT THE IMPACT OF SIMILAR MATERIAL CUTOFFS?

THE POINT IS, PRICE HAS ALWAYS BEEN A SHORT RUN FACTOR. IN 1981 WE CANNOT ONLY AFFORD TO BE CONCERNED WITH JUST SHORT RUN FACTORS.

AND CLAD METALS, BE THEY ROLL OR EXPLOSIVE BONDED OR WELD OVERLAY, DO OFFER A VIABLE ALTERNATIVE TO SOLID ALLOYS WITH BOTH SHORT AND, MORE ESPECIALLY, LONG RUN ADVANTAGES.

PRESENTATION BY
JAMES M. GLAZEBROOK
MANAGER, HEAD AND CLAD SALES
LUKENS STEEL COMPANY

CONSERVATION OF CRITICAL METALS UTILIZING SURFACE ALLOYING

Ray J. Van Thyne

Dilex Systems

CONSERVATION OF CRITICAL METALS UTILIZING SURFACE ALLOYING

Ray J. Van Thyne*

Summary

Surface alloying offers a significant opportunity for conserving chromium and other critical metals. Surface alloying is discussed generally and the Dilex process for surface alloying of ferrous products in a molten lead medium is described. The Dilex process offers technical and economic advantages, and the opportunity to produce unique materials. A wide range of materials offering resistance to corrosion, oxidation, and wear have been produced.

* Dilex Systems, Material Sciences Corporation,
1909 S. Busse Road, Mount Prospect, Ill. 60056 (312) 437-9855

CONSERVATION OF CRITICAL METALS UTILIZING SURFACE ALLOYING

I. Introduction

Surface alloying offers a significant opportunity for conserving critical metals such as chromium. Elements are utilized in the most effective manner by placing them on the surface where they are required for corrosion, oxidation or wear resistance. Surface alloying may be accomplished by various means such as high temperature diffusion, selected surface melting or ion implantation. The former is the most common.

This paper will describe several methods of surface alloying but will focus on the Dilex process which involves diffusion alloying, principally of ferrous products in a high temperature lead medium.

II. CONSERVATION OF CHROMIUM AND OTHER CRITICAL METALS

It is obvious that replacing solid stainless steel with chromized or other surface alloyed products results in considerable reduction in usage of chromium. In typical small fabricated parts, a 3 mil chromized surface layer accounts for only about 6% of the total volume of the part. In chromized steel sheet with a 3 mil layer on both sides of a 40 mil sheet 15% of the cross-section is stainless steel.

Although the average chromium content of the chromized layer is somewhat higher than in homogeneous stainless steel (23% versus 18% typically), chromium savings are over 80%. Surface alloying offers opportunities for further savings in chromium by multiple alloying, i.e., replacement of part of the chromium content by aluminum in an oxidation resistant material, or conservation of other alloying elements by use of other surface alloyed steel or stainless steel to replace more premium materials.

Chromized steel is a candidate substitute for homogeneous stainless steel in many applications. Corrosion and oxidation resistance are surface properties and the material need have these properties only for some finite practical distance in from the surface to provide a reservoir of alloyed material and to provide for scratch and abrasion resistance. Although platings and other coatings have been considered as substitutes

for bulk stainless steel, they have met with limited success since they do not have the required surface properties and are prone to coating defects. Such coatings generally have poor mechanical properties, are not well bonded to the substrate, and will delaminate or crack during forming. The formability of surface diffusion alloyed mild steel is similar to, and in many cases better than, stainless steel. For sheet applications the exposed cut edge must be accommodated through design or fabrication. Stainless steel welding techniques are successfully used. Surface alloyed mild steel has lower strength than stainless steel which will limit its use in applications requiring higher strength at ambient or elevated temperatures.

The substitution of surface diffusion alloy products for homogeneous stainless steel has been very limited to date. Further expansion of this market will depend upon additional developmental work, pilot production to supply limited quantities of material to potential users to develop fabrication and application experience, and capital investment to produce certain products. This is a relatively long process since field tests often require one year.

III. SURFACE ALLOYING PROCESSES

Surface alloying is generally used because of cost effectiveness or the ability to produce special properties or composite materials. Selected composite properties of interest are shown in Table I. Some of the processes available are given in Table II. Materials are exposed to a wide range of hostile environments experienced in such applications as petrochemical, coal gasification, chemical spray nozzles, marine, and various consumer products. Chromizing is the surface alloying process that has received the greatest attention and a diffusion curve is shown in Figure 1.

Typical commercial applications of surface alloying include coated gas turbine hardware for oxidation resistance, and aluminized tubing in petrochemical heat exchangers for sulfidation - and oxidation-resistance. Pack chromizing of parts is being performed on a limited basis. Chromized steel sheet produced by rolling of ferrochrome powder on the surface of steel followed by diffusion annealing was commercially available until recently. The largest single use of this material was in gas-fired heat exchangers in commercial furnaces. The chromized steel was preferred to stainless steel because of its superior corrosion resistance resulting from the higher surface chromium content, and the material provided a manufacturing advantage compared to stainless steel of less spring-back in forming.

A number of metal treating techniques are available using ion processing including ion implantation. This is in the development

TABLE I

COMPOSITE PROPERTIES BY SURFACE ALLOYING

Corrosion Resistance + Thermal

Different Surfaces on Tubes

Corrosion Resistance + Magnetic

Corrosion/Oxidation + Fabricability

Ferritic/Austenitic Avoid Stress-Corrosion

TABLE II

SURFACE ALLOYING METHODS

PACK CHROMIZING, ALUMINIZING, BORONIZING

GAS TRANSPORT

DEPOSIT FERROCHROME POWDER AND DIFFUSE

LASER, PLASMA TORCH, ION IMPLANTATION

SALT BATH CONTROLLED DEPOSITION

DILEX LIQUID METAL TRANSFER

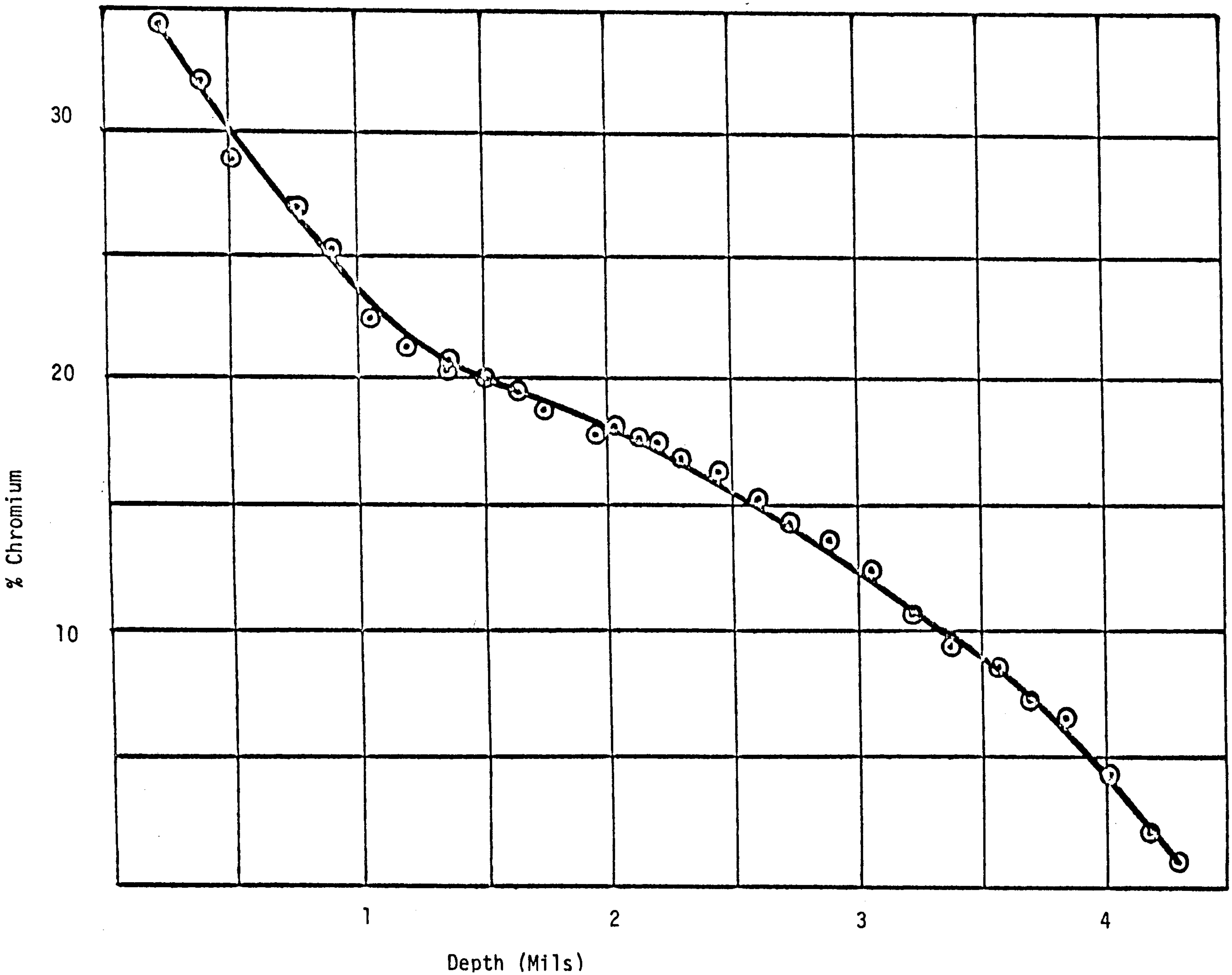


Figure 1 Chromium Diffusion Into Iron

stage and involves a plasma of ions driven by an electrical charge. The resultant surface alloy is extremely thin and in the range of 500 to 3000 Å. Implantation of chromium has been considered for improving corrosion of aircraft bearings during shelf storage prior to use. A major advantage is that the substrate remains cool during processing.

Although laser drilling, welding, and heat treatment is commercial, laser alloying is generally in the development stage. It offers opportunities for good control, selected area treating, and limited heating of the substrate. Chromium and aluminum have been alloyed into ferrous surfaces and carbide has been fused into the surface of aluminum. In layerglazing, a thin layer of the substrate is melted with an alloy addition and extremely rapidly self-quenched. Also Stellite 6 has been laser clad on steel with only limited interalloying.

Wear resistant surfaces are produced by pack or salt bath boronizing. Metal carbides are formed by reaction of infusing metals and carbon in the steel.

IV. DILEX PROCESS

The Dilex process involves diffusion surface alloying principally of ferrous products in a lead medium and offers advantages over alternative processes. A wide range of useful elements shown in Table III may be controllably transferred. The elements are listed in descending order of dependency on imports. Constituents that cannot be diffusion treated may be prealloyed into the substrate. Multi-alloying by co-diffusion has been demonstrated. Unique materials of a composition and form that would be very difficult to make by other metallurgical processing methods have been produced. The molten lead readily contacts all surfaces and is a highly efficient alloy transport medium thus resulting in very uniform alloying, and intricate shapes may be processed.

In the principal step of the process, the ferrous product is immersed in lead within a retort and alloying additions such as ferrochromium are included in a screened cage. Lead melts at 620° F and typical processing temperatures are 1850° F to 2050°. Surface alloying occurs by simple metallic diffusion; no chemical or electrochemical processes are involved. Molten lead is an ideal medium and exhibits a number of useful properties for this application as follows:

1. Inexpensive and readily available
2. Reuseable and refined by skimming off impurities that float to the surface.

TABLE III

TRANSFERRED BY DILEX PROCESS

MANGANESE

COBALT

CHROMIUM

NICKEL

TITANIUM

ALUMINUM

3. Rapid heating and cooling because of the high heat transfer with relatively low enerby consumption (the specific heat of lead is about one-third that of steel)

4. Low vapor pressure of molten lead allows it to be readily handled in the open at temperatures of 800^{O}F and negligible pressurization occurs in sealed retorts since the vapor pressure is less than 0.1 psi at 2000^{O}F

5. A molten metal medium facilitates continuous processing if desired

6. Compatible with steel and stainless steel since the solubility of iron in molten lead is about 0.01% at 2000^{O}F

7. Lead is insoluble in steel

8. Solute transfer through the molten lead is rapid even though alloying solubilities may be low; for example, the solubility of chromium is 0.05% at 2000^{O}F. An excess of chromium may be used with the chromium dissolving into the bath as required

9. The only processing controls are temperature and time if excess alloying additions are used

10. After processing, lead is readily removed from the treated product by mechanical,chemical dissolution and/or de-wetting procedures

11. Multiple alloyed products can be produced

Chromizing at $2050^{O}F$ for four hours produces a 0.004 inch thick stainless steel layer and requires a total batch processing cycle time of about 20 hours. The lead holding retorts are electrical radiant heated and are constructed of type 304 stainless steel with an outer shell of Inconel 617 over the bottom portion for increased high temperature oxidation resistance and strength. Retorts are only opened at temperatures below $1000^{O}F$ and are sealed under an inert gas at more elevated temperatures. A periodic vertical motion is imparted to the load, which is accomplished by a drive shaft through the cover. Retorts up to 33 inches in diameter shown in Figure 2 have been operated.

Components that have been treated on a developmental basis include: open wrapped coil, foil, fabricated components, short length tubing, and a variety of small machined, cold headed, or PM parts. The small parts are fixtured (Figure 3) or treated loosely, depending upon the requirements. With loose parts, some relative motion, such as by agitation must be provided about every 5 minutes to avoid bonding. Only batch processing has been employed to date, but continuous throughput processing is feasible.

To achieve excellent corrosion resistance with simple chromizing, interstitial element control of the steel is necessary. Free carbon in the steel will react with infusing chromium causing sensitization. Accordingly, a steel with negligible carbon or a special substrate steel is required. One steel that has been successfully treated is commercially available IF steel (0.01 C,

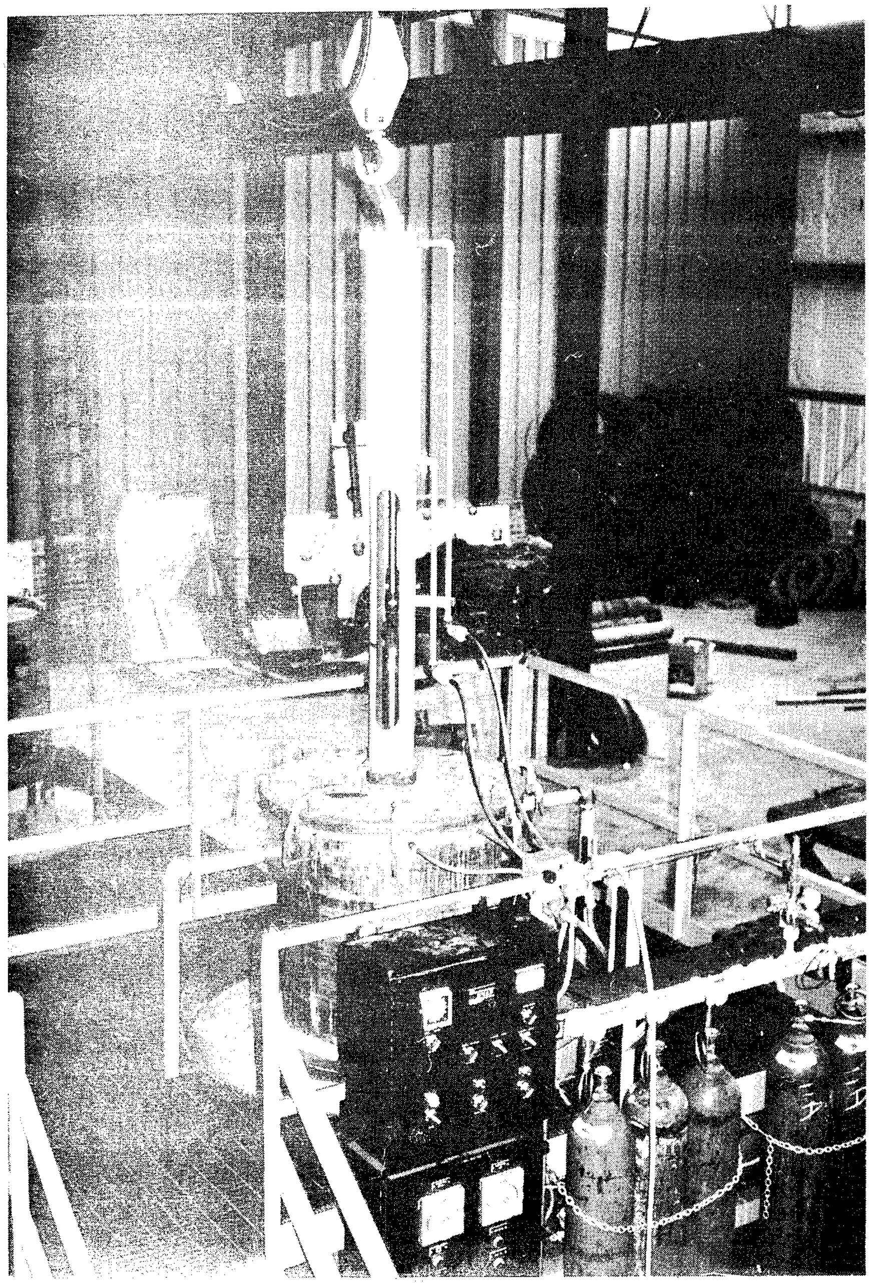


Figure 2 Dilex Reactor

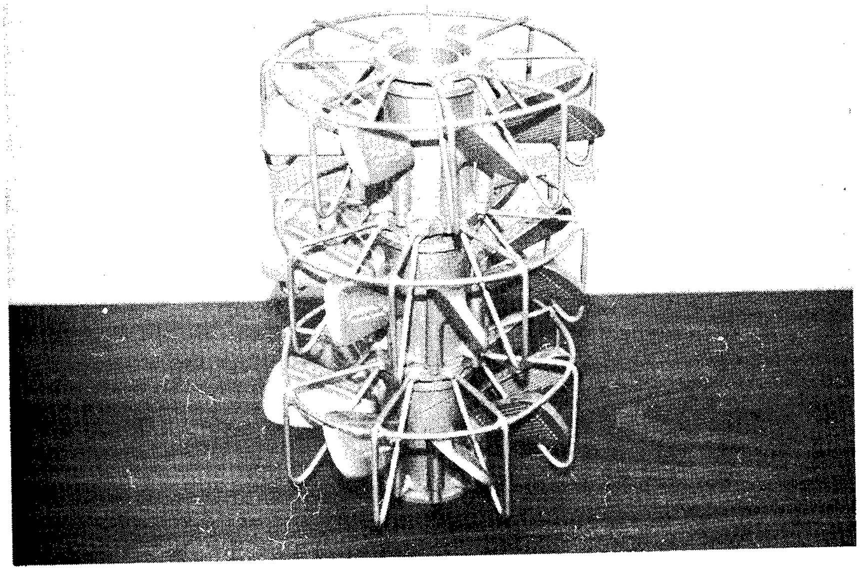


Figure 3

Fixtured Parts for

Dilex Processing

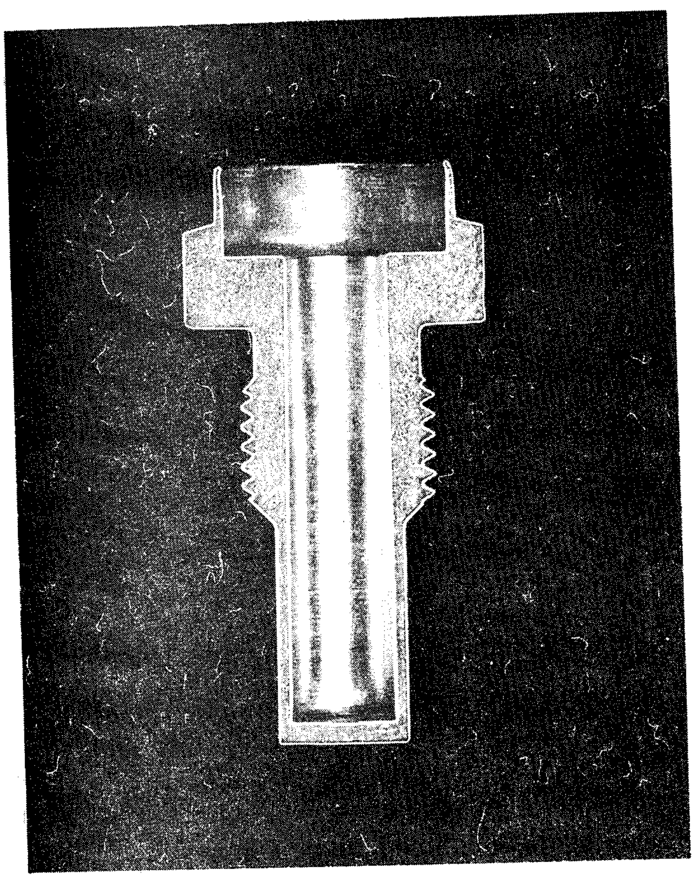


Figure 4

Dilex chromized part, sectioned and etched to show the uniformity of the Dilex layer X 1.5

0.03 Al, 0.04 Ti, 0.04 Cb). Current work on Dilex co-alloying may allow a broader range of steels to be accommodated.

The Dilex surface alloy layer is extremely uniform as shown in Figure 4. This is a sample sectioned after chromizing and immersing in boiling nitric acid which attacks any composition lower than 12% chromium. The sharply defined boundary seen in the sample is a chemical rather than a physical boundary. The surface layer is not a coating as Figure 4 might indicate and cannot delaminate from the substrate. Semi-tubular rivets treated by the Dilex process withstand setting of 90° without damage to the alloyed layer. The uniformity of the Dilex chromized layer on sheet is illustrated in Figure 5. Densification of the outer layer occurs during surface alloying of PM materials (Figure 6). A growth of about one mil accurs with a 5 mil Dilex chromized layer.

Certain parts that would be difficult or impossible to cold head from solid stainless steel may be made from low carbon steel and then treated by the Dilex process. Cost savings up to 25% may be achieved in Dilex treatment of various low carbon steel parts made on screw machines, compared to stainless steel. Although some material savings result, the principal advantage is the substantial reduction in machining costs. However, the inclusions present in free machining steel degrade the corrosion resistance.

Small experimental batches of low carbon steel wire have been chromized by the Dilex process. This wire was cold drawn to 92% reduction in area without any cracking or delamination. This cold worked wire exhibited a tensile strength of 90,000 to

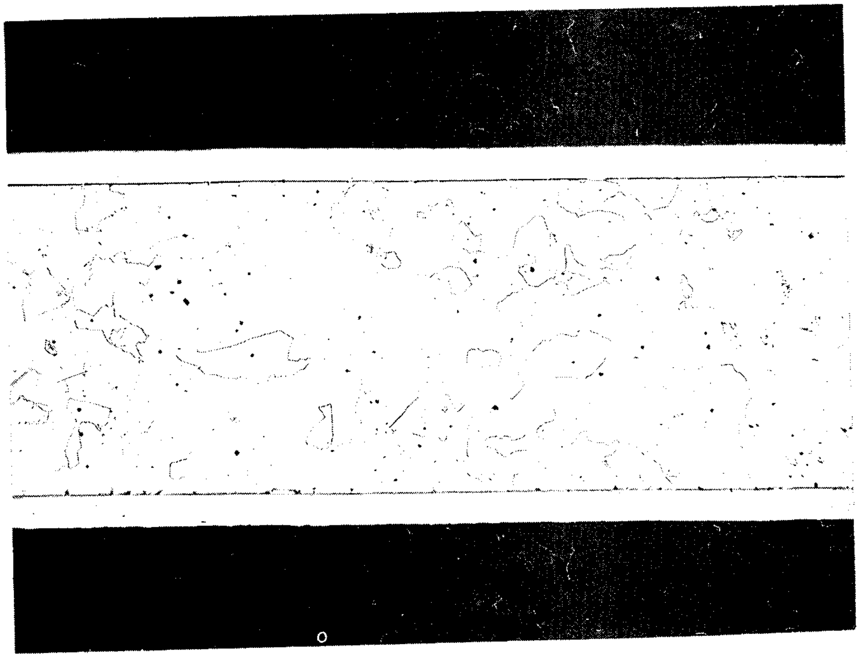


Figure 5

Dilex chromized sheet

Nital etch X 50

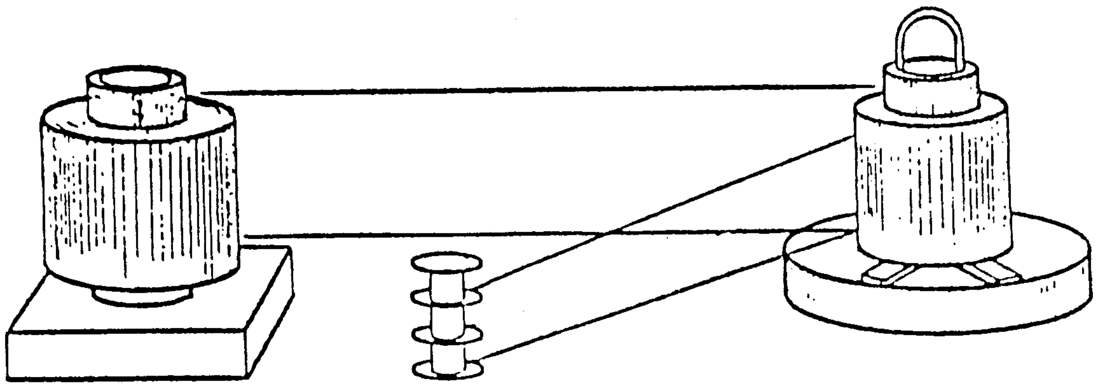
Figure 6

Dilex chromized PM showing densification. Nital etch X 125

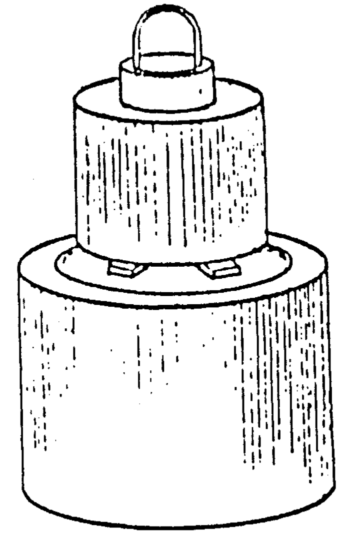
100,000 pounds per square inch with 7% elongation. This strength is low compared to cold drawn stainless steel wire. Dilex treated wire drawn to 76% reduction in area exhibits strength similar to wire drawn to 92% reduction in area. Salt water immersion tests of 100 hour duration were performed on the wire after 76% cold reduction in area. No rust spots were evident after testing, which demonstrates the integrity of the Dilex layer. Wire would be processed on a continuous through-put process using multiple strands.

Many 1000 pound coils 24 inches wide have been produced on a developmental basis. These were processed as open wrapped coils, and it has been demonstrated that the lead medium provides uniform surface alloying even with very narrow spacing between the circumferential wraps. A two strand twisted wire inserted into each edge of the coil during wrapping provided a 0.090 inch spacing. The sheet operations are schematically illustrated in Figure 7, and a processed coil is shown in Figure 8. A heat shield is located above the coil, and a single screened cage for holding the alloy charge is on the bottom.

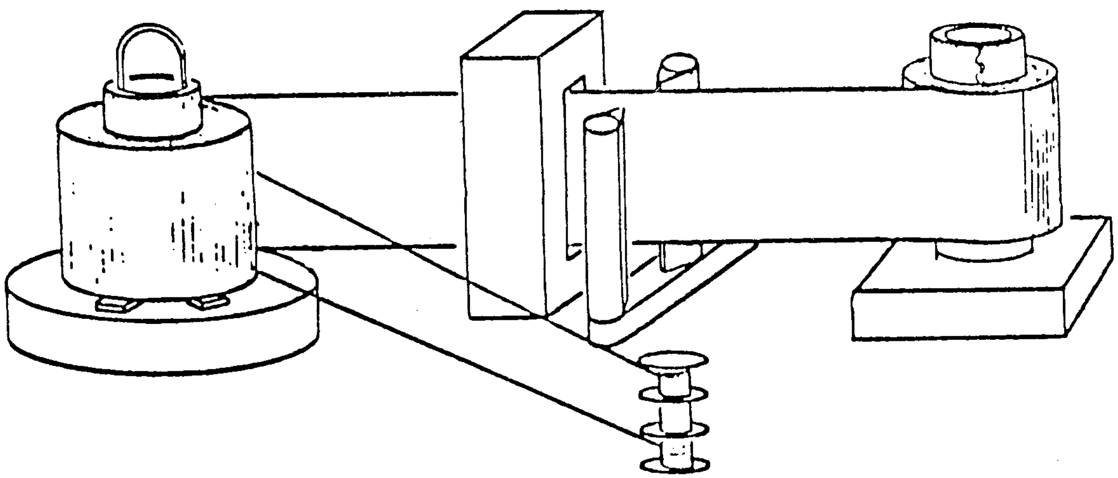
The substrate was IF steel. The final thickness may range from 6 to 100 mils. Generally, the steel coils were treated by the Dilex process, cold rolled, annealed, and temper rolled. The steel sheet was treated to yield a thicker initial layer and provide a 3 mil final thickness after fabrication. A 0.007 inch thick chromized layer which would be cold rolled 50% is produced in 12 hours at 2050^{O}F and requires a total processing cycle time



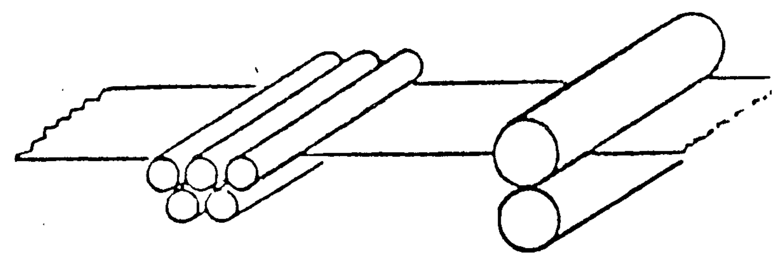
(1) OPEN COIL WINDING WITH SPACER WIRES



(2) SPACED COIL IMMERSED IN LEAD BATH



(3) SPACER WIRE REMOVAL AND DELEADING



(4) ROLLER LEVELING AND FINISHING

Figure 7 DILEX DIFFUSION ALLOYING SHEET OPERATIONS

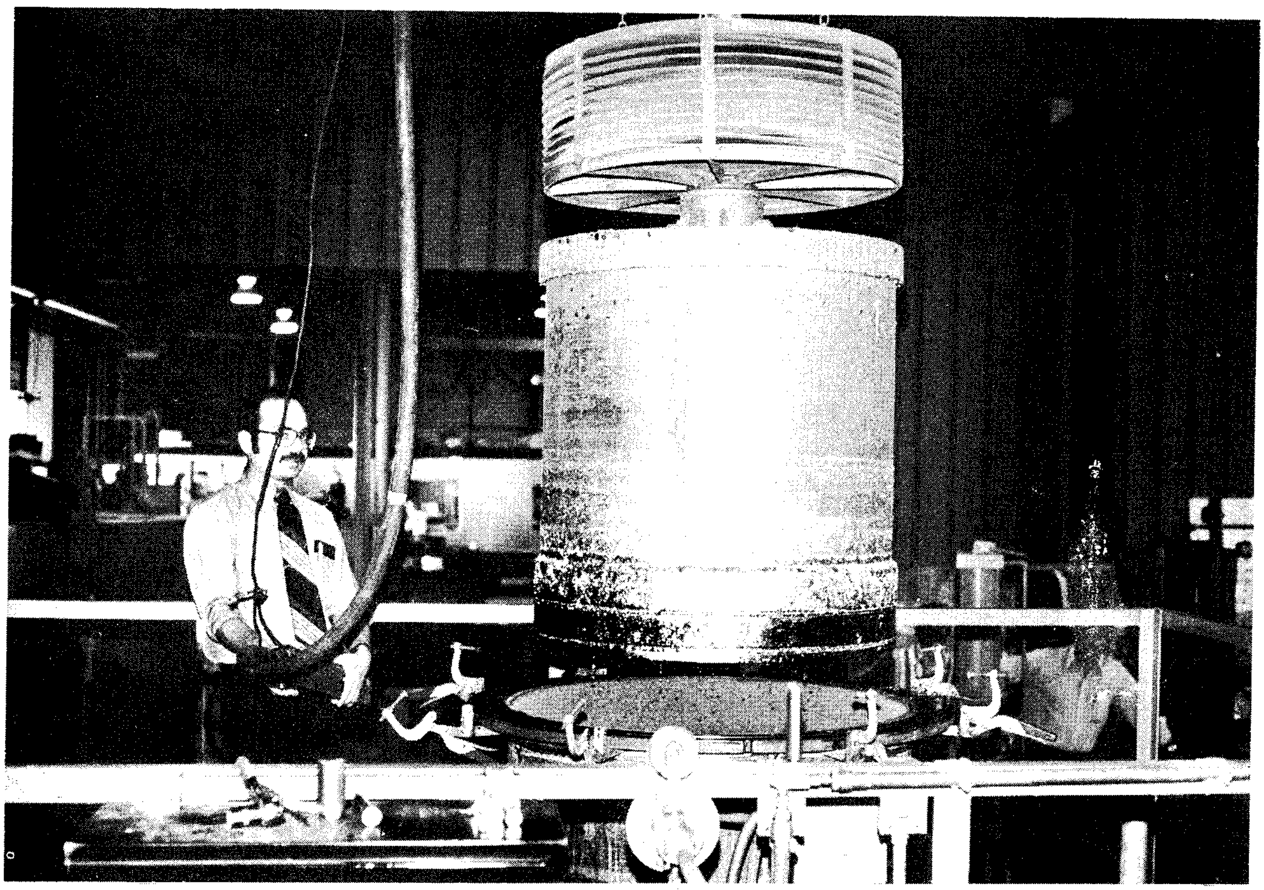


Figure 8 Dilex Chromized Steel Coil

of 30 hours. The corrosion properties were competitive with type 430 SS. The mechanical properties were reduced compared to stainless steel. Sheet material in the temper rolled condition with an ASTM grain size of 6 has typical properties of 43,000 psi tensile strength, 28,000 psi yield strength, and 35% elongation. Higher strengths can be achieved by greater amounts of residual cold working. The formability of the material is excellent as evidenced by a 2 inch diameter cupping test and a 6 inch box made from a 12 inch diameter blank shown in Figure 9.

Batch treated Dilex chromized open wrapped coil does not presently offer cost savings over the cheaper grades of stainless steel; the projected Dilex processing cost is about $0.30 per pound of 20 gage (0.036 inch thick) sheet based upon processing of 20,000 pound coils and production of 10,000 tons per year. This cost does not include the starting steel or cold rolling after Dilex treatment.

The Dilex processed surface is smooth. Even though substantial material is added through surface alloying, fine details such as scratches from machining are replicated. The resultant surface finish as Dilex processed is about 80 rms, which is equivalent to a machined surface. For sheet applications, the exposed cut edge must be accommodated through design or fabrication methods.

The generation of special alloys and structural shapes are important parts of the Dilex technology. As shown in Figure 10, an Fe-Cr-Al surface alloy is produced. It has excellent oxidation resistance to 1700^{o}F. By regulation of the aluminum addition, the level can be controlled over the range of 0 to 25% to

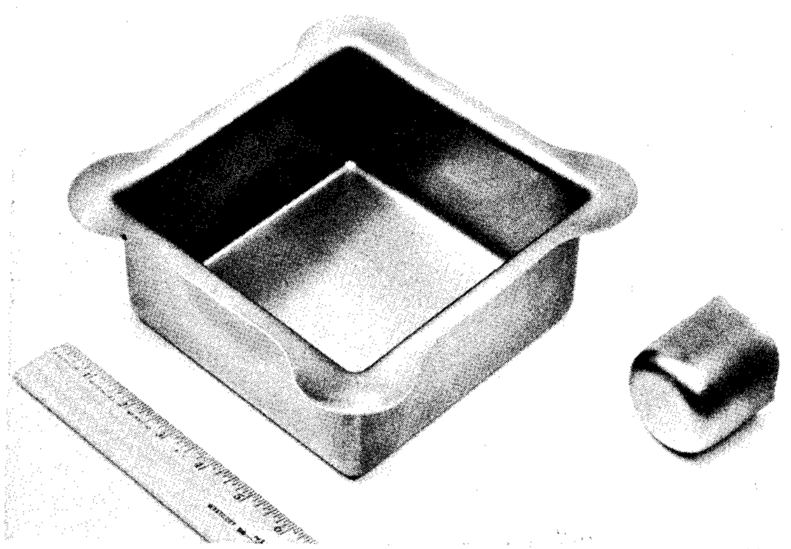


Figure 9 Formability Tests on Dilex Chromized Steel Sheet

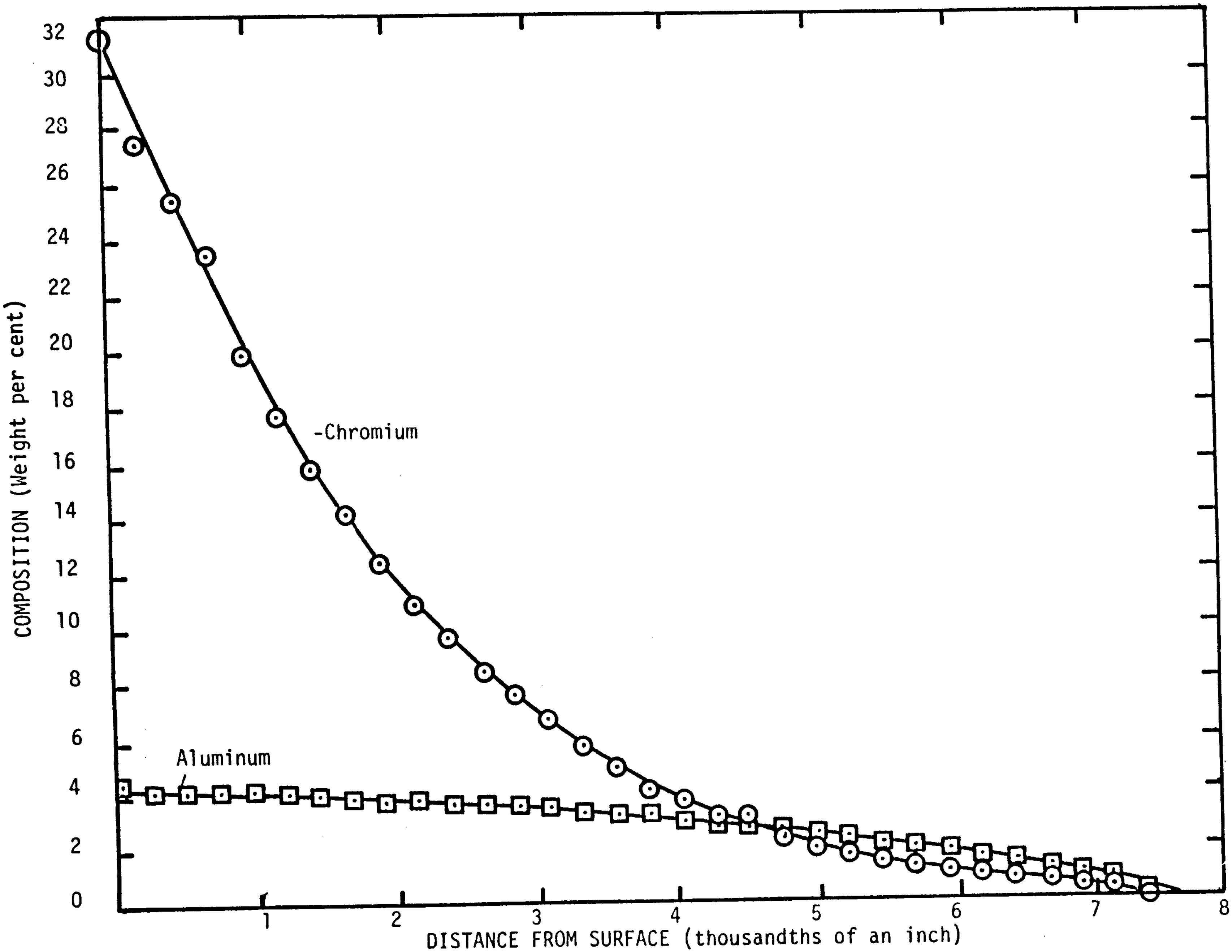


Figure 10 CONCENTRATION - PENETRATION CURVE FOR STEEL SHEET CO-ALLOYED WITH CHROMIUM AND ALUMINUM BY THE DILEX PROCESS

yield a desired combination of properties. Various other alloying elements may be employed to diffusion alloy steel or up-grade type 430 or 304 stainless steel to compete with more premium materials. In many corrosion applications, the lower strength of the surface alloyed materials will not be a problem.

Various structural shapes have been treated by the Dilex process. Heat regenerator structures made of 2 mil corrugated steel foil 3 inches thick have been through-alloyed to produce typical compositions of Fe-22Cr-4Al. During processing, bonding occurs at all nodes where contact occurs as shown in Figure 11.

Alloying constituents that are transferred in the Dilex process may also be removed from the ferrous surface. By removing nickel and/or adding chromium, a ferritic layer is produced on type 304 stainless steel than is more resistant to stress corrosion. This has been confirmed by U-bend tests in boiling 42% magnesium chloride. The test was terminated after 690 minutes; the untreated type 304 stainless steel showed serious cracking (Figure 12), but the Dilex treated material exhibited no cracking.

Two mil thick foil has been through-alloyed. In this manner highly alloyed compositions may be made at or near final gage. Equivalent compositions produced by conventional practices would be extremely difficult to fabricate.

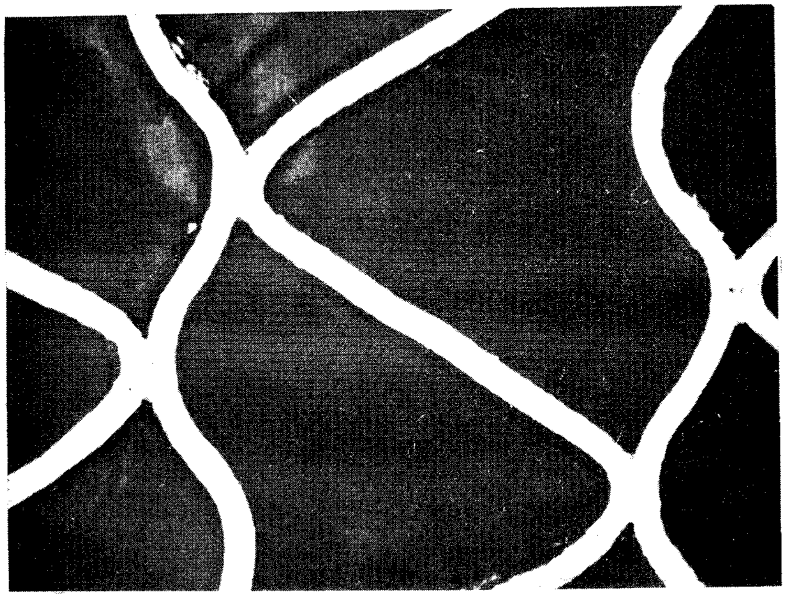


Figure 11
Two mil foil corrugated structure illustrating through-alloying and bonding. Metal etch X 70

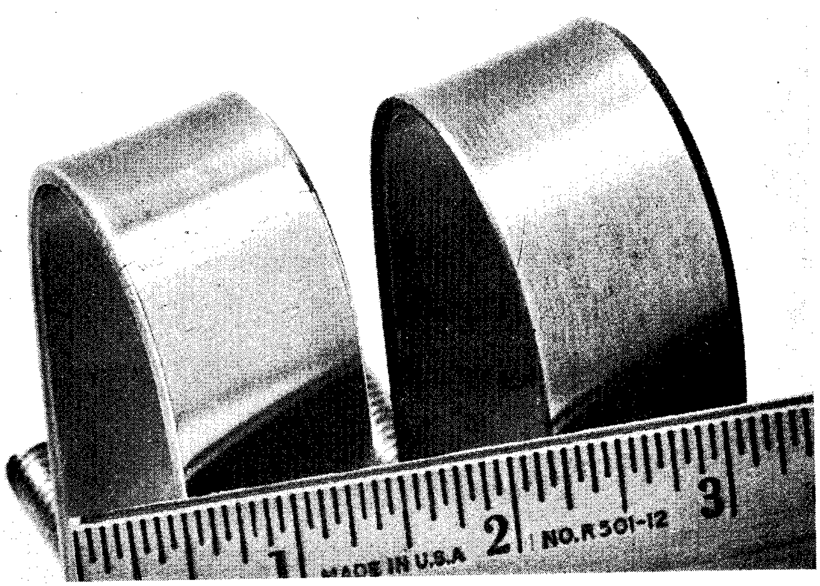


Figure 12
Samples illustrating stress-corrosion cracking in 304 stainless steel and no cracking in Dilex treated 304 stainless steel.

IV. WEAR RESISTANT MATERIALS

Surface alloying offers the opportunity of producing hard wear resistant materials, and various methods may be used. When steels containing over 0.30 percent carbon are chromized, a continuous chromium carbide layer, typically up to 1 mil thick, is formed. This layer has a hardness of about 1800 DPN (50 g load) which is about twice that of hard chromium plate and about equal to that of commercial tungsten carbide. The chromium carbide layer that is formed will allow subsequent heat treatment of the steel without spalling. The combination of a high hardness layer backed up by a hardened tough steel is desirable. Preliminary evaluations include a forming punch and erosion resistant nozzles. Dilex processing offers the possibility of producing other carbides having higher hardness than chromium carbide, such as titanium carbide or mixed carbides.

ELECTRON BEAM IRRADIATION APPLIED TO CONSERVATION OF CRITICAL MATERIALS

Joe E. Jenkins

Leybold-Heraeus Vacuum Systems Inc.

ELECTRON BEAM IRRADIATION
APPLIED TO
CONSERVATION OF CRITICAL MATERIALS

Paper prepared for the
"Workshop on Conservation and Substitution
Technology for Critical Materials"

15-17 June 1981
VANDERBILT UNIVERSITY
Nashville, Tenn.

By

Joe E. Jenkins
Senior Metallurgist
LEYBOLD-HERAEUS VACUUM SYSTEMS INC.
Enfield, CT

Conservation of critical materials by irradiation with an electron beam may be accomplished in several ways. Among these is rapid surface fusion to refine the grains in metals and alloys. A rapid surface fusion can result in subsequent high solidification rates, the benefits of which are now being extolled in the technical press and at conferences. Strutt, Nowotny, Tuli & Kear have reported on laser processing, and Strutt and the Writer have reported on electron beam processing, References 1, 2, and 3.

Depending upon the alloy being treated and the specific process parameters, a high degree of grain refinement with metastable solid solutions is likely. In the case of steel and cast iron, an extraordinarily high hardness level is obtained that is relatively insensitive to cracking.

Wear resistance is a materials property that is difficult to measure with accelerated laboratory tests. Hardness has been used as a basis for estimating the relative wear resistance by designers. This is a convenient measurement to make in estimating the effect a rapid surface fusion may have on wear properties.

AISI 1045, 4150, and 1090 steels have recently been electron beam glazed in our laboratory. In each instance, an extraordinarily high hardness level is obtained. Figure 1 compares the hardness due to glazing with that from conventional quenching. Note that the glazed hardness exceeds HRC 65 for all materials. We believe this high order of hardness is useful because the glazed layer appears to have some toughness. Figure 2 shows adjacent, superimposed and edge microhardness indentations with no indication of cracking in AISI 4150 steel at HRC 67. Glazing may eliminate the need for expensive, critical materials to develop hard wear resistant surfaces in certain practical applications.

Aluminum alloys also respond to glazing. Figure 3 is a photomicrograph of a section taken through a path glazed with a high power electron beam in Alloy 319. The glazed material is on the left in the micrograph. This was done with the alloy at atmospheric pressure by use of the non-vacuum electron beam process. The solidification rate was adequate to afford a high degree of refinement in the grain structure. Microhardness tests show the glazed layer to be HVN 111 and the untreated material to be HVN 78. This is enough increase to permit an auto engine part to function with no inserted wear pad.

We are developing successful application of electron beam glazing on a diesel engine part made from modular iron. Direct high rate surface fusion has replaced cobalt base and/ or high chromium hard facing in experimental parts. Figure 4 shows two views of a treated part. The fusion is explicit. Treatment time was two seconds.

Figure 5 shows a longitudinal section of a similar part processed by hard-facing, and one electron beam glazed. The savings in critical alloys is obvious. In addition, it appears that the reject rate can be reduced, as subsequent spot hardening treatment causes some cracking at the hardfacing interface. The time to finish grind can either be eliminated, or reduced to a small percentage of that currently required. EB processed parts are being engine tested "as treated" as well as with a light post glaze grind. In either event, appreciable process time, finish time and critical alloy is saved.

Figure 6 is a plot of microhardness survey data taken on a section after treatment. Superimposed on this plot is a photomicrograph of a section taken through a glazed area. Note the extreme hardness of the refused layer which extends to a depth of 3/4 of a millimeter. Under this layer, a layer of white iron is developed having slightly less hardness, to a total depth of 1.5 millimeters.

Figure 7 is a photomicrograph of the fusion - white cast iron transition. The recast layer (at the top) consists of a fine cementite (Fe_3C) dendritic structure in an austenitic matrix hardened by precipitation of Fe_3C and perhaps some graphite. These structure details measure HVN 800-1100 (equivalent HRC 64-70X). These microhardness data were obtained with a 25 gram load.

In engine tests, these electron beam treated parts are doing well at last report, and are well on the way toward a 10,000 hour test objective.

Savings in chromium, vanadium, tungsten, and molybdenum are effected through discrete use of high speed steel. Electron beam welding permits just the teeth of band saw blades, among others, to be high speed steel with the blade body made of low alloy steel. Figure 8 shows a piece of welded band saw blade stock.

Figure 9 is a photomicrograph of a section through this stock. The weld is approximately 0.25 mm wide, and is made at speeds up to 18 meters/minute. Approximately 95% savings in high speed steel is effected, with an improvement in quality!

This bi-metal idea has been used in production since 1968. However, accelerated use of this electron beam welding technique has been experienced in recent years due to the increasing cost differential of the tool steel and the increase in modern equipment which is 2 to 3 times more productive than the earlier systems.

This same philosophy is being persued with thicker, more massive cutters. Tools having welds up to 20 mm deep have been made successfully in the laboratory. Several applications are pending.

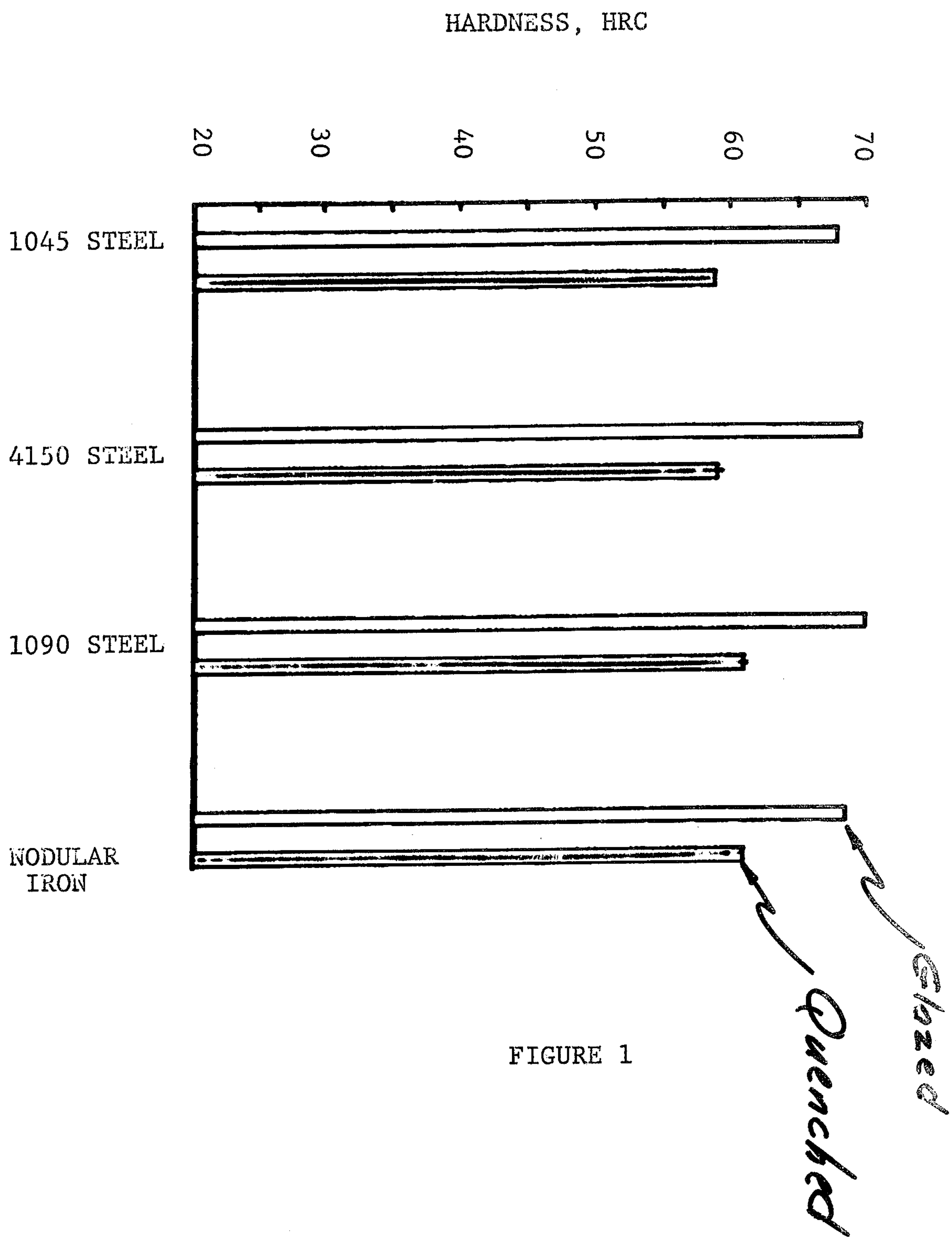
Surface modification through electron beam glazing and discrete use of high alloy through electron beam welding have saved thousands of tons of critical material and hold promise of effecting savings at an increasing rate in the future.

REFERENCES

1. P. R. Strutt, H. Nowotny, M. Tuli & B. H. Kear Materials Science & Engineering 36 (1978) 217.

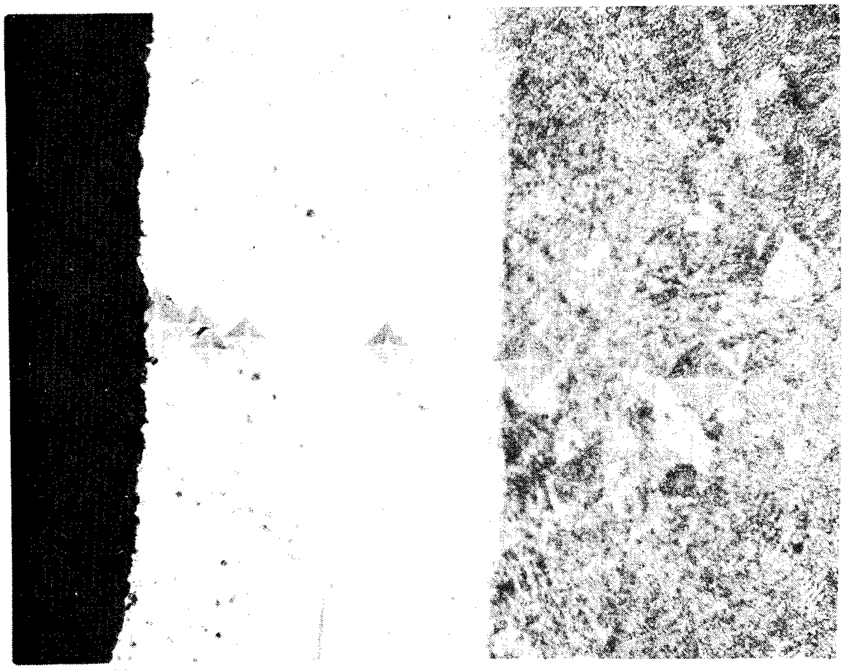
2. P. R. Strutt, Materials Science & Engineering 44 (1980) 239.

3. J. E. Jenkins, International Conference on Metallurgical Coatings, Abstract Book P10, San Francisco, 1981.



GLAZED HARDNESS COMPARED WITH QUENCHED HARDNESS

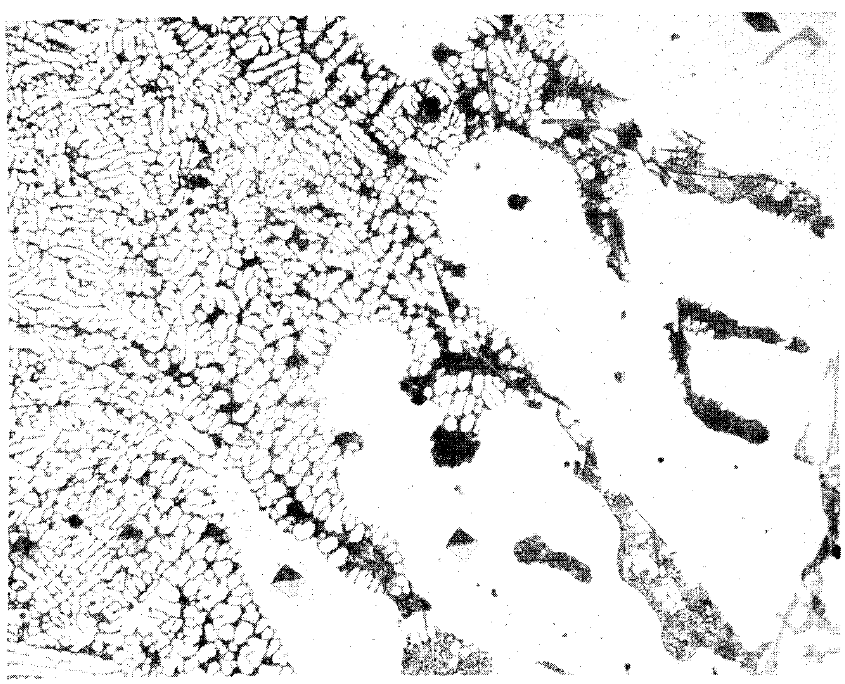
FIGURE 1



600X

Superimposed Hardness Tests
In Glazed Layer AISI 4150 Steel

FIGURE 2

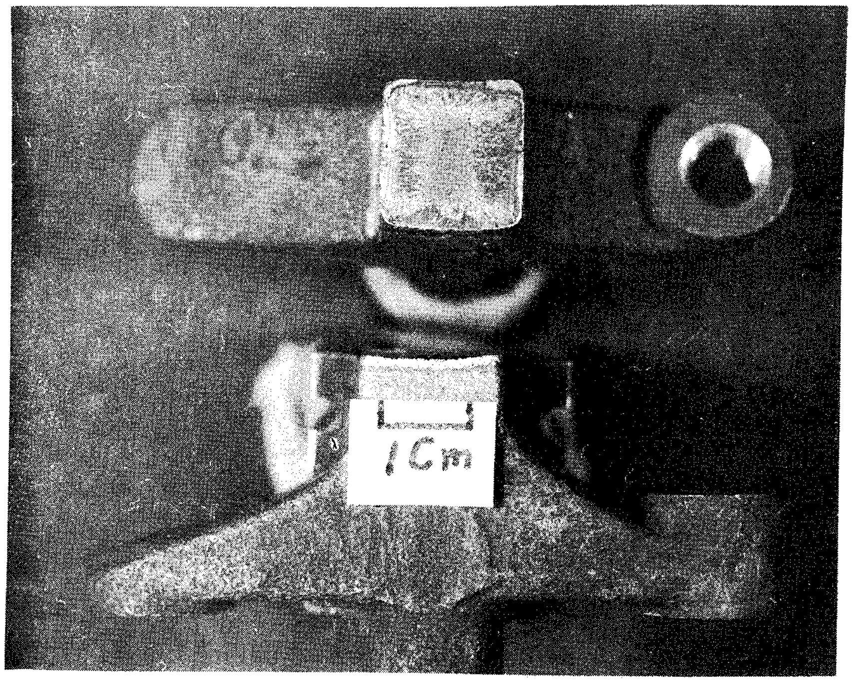


Glazed

Parent Metal

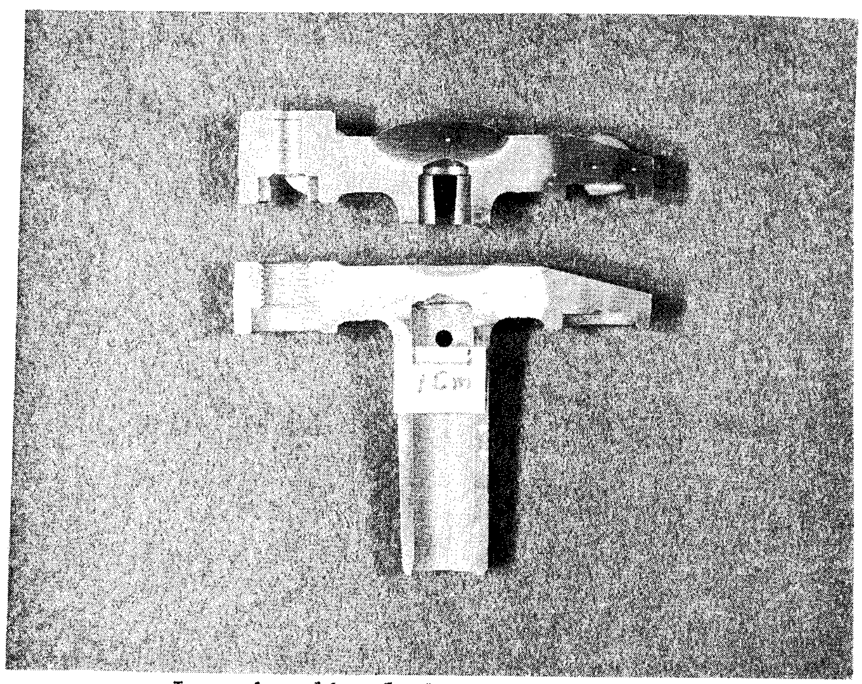
Glaze Transition
Aluminum Alloy No. 319

FIGURE 3



E. B. Glazed Engine Part

FIGURE 4



Longitudinal Sections of
Hard Faced Part (Top) &
E.B. Glazed Part

FIGURE 5

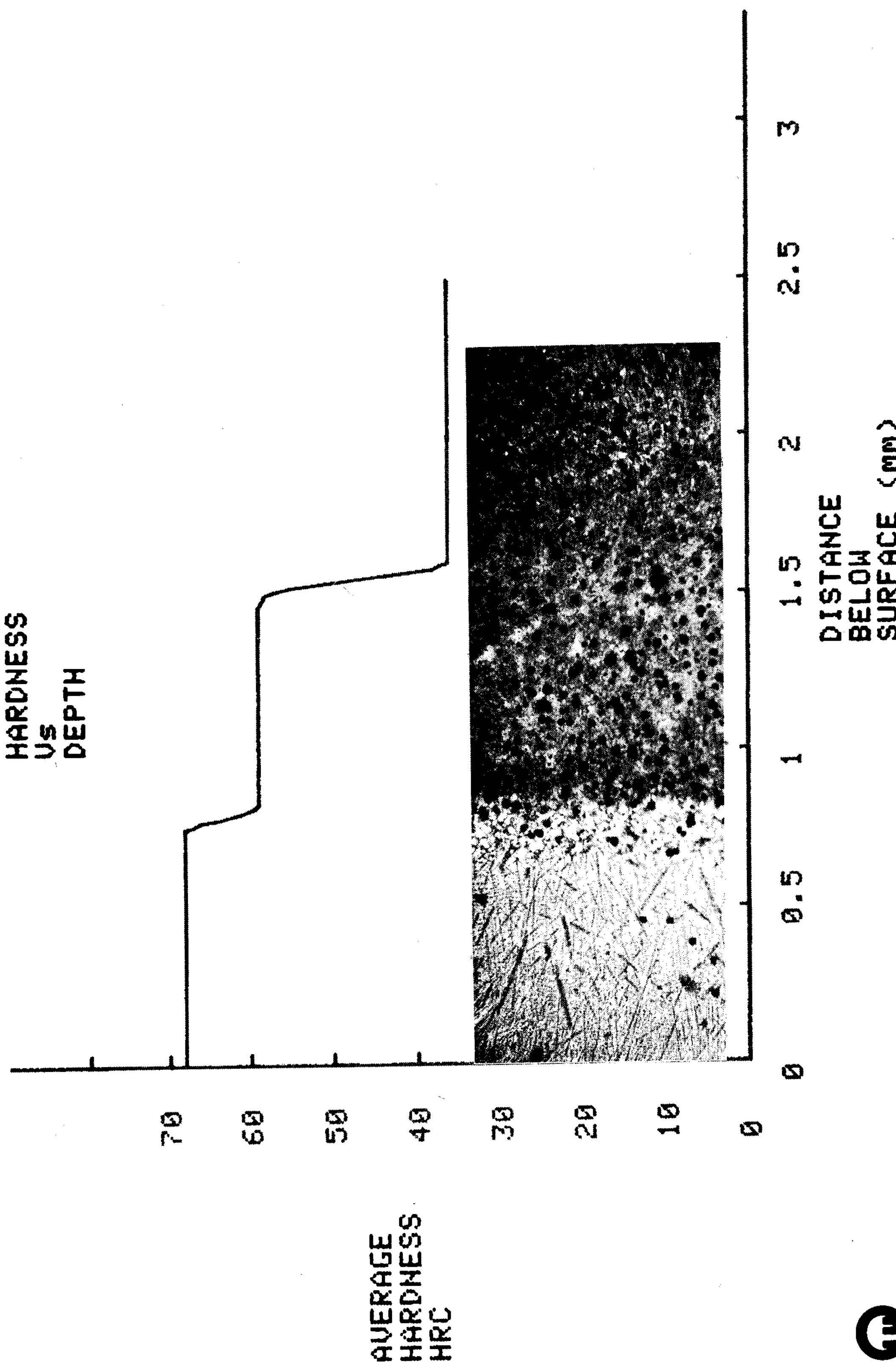


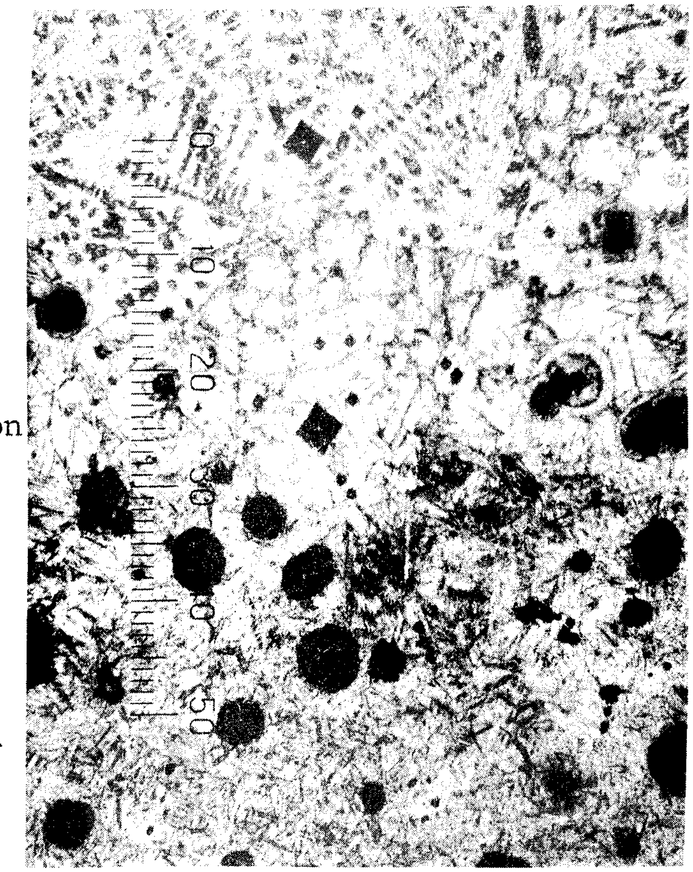
FIGURE 6

PCC-11

Glazed

Glaze Transition

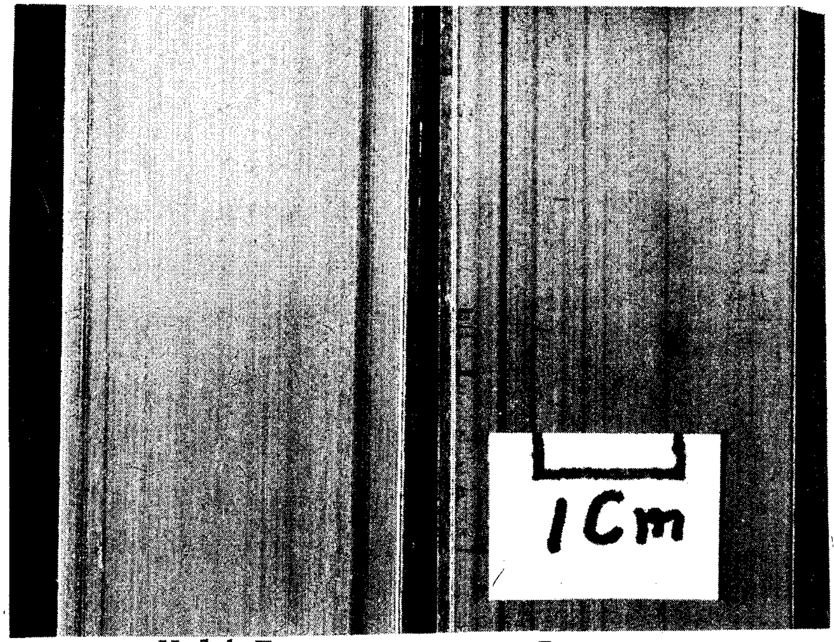
"White" Nodular
Cast Iron



300X

Glazing Transition

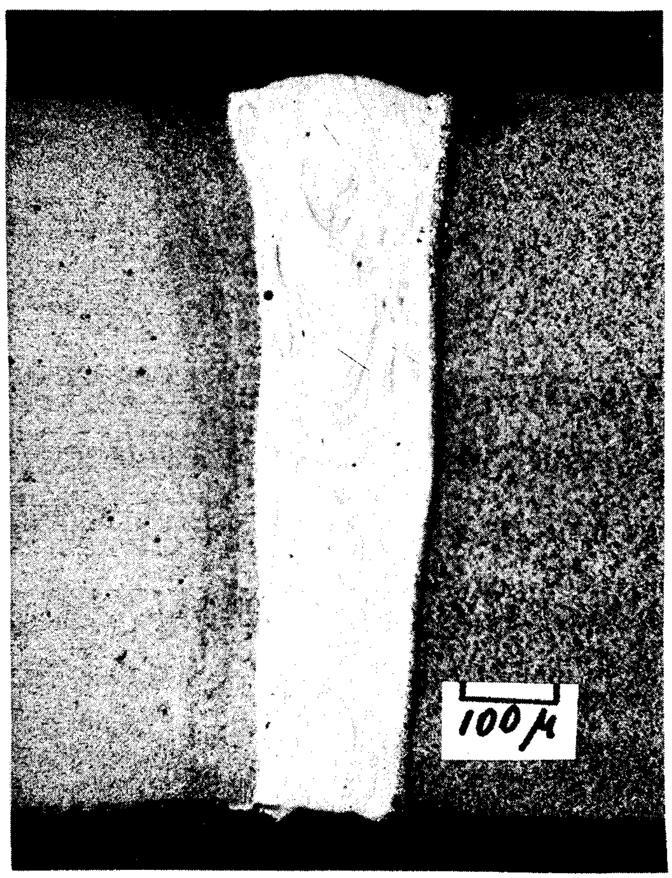
FIGURE 7



Weld Face Root

E.B. Welded Saw Blade Stock

FIGURE 8



Cross Section Through Weld

FIGURE 9

APPLICATION OF THERMAL SPRAYING PROCESSES TO CONSERVE CRITICAL MATERIALS

Edward R. Novinski
METCO Inc.

APPLICATION OF THE THERMAL SPRAYING PROCESSES TO CONSERVE CRITICAL MATERIALS

Edward R. Novinski
METCO INC.

BACKGROUND

Over the past decade, the United States has seen the head-on effects of the national crisis in energy and the environment. Both have markly commanded public attention and have resulted in economic and social realignment. The growing problem of material shortages is rapidly becoming the nation's next challenge. The United States has an enormous appetite for both energy and materials. With only six percent of the world's population, we consume 30% of its energy.(1) Materials consumption is more difficult to assess. However, the United States chromium ore utilization in 1977 represented 25% of all world production.(2) The supply of critical metals and minerals is heavily dependent on political and economic factors set by foreign sources. The long range supply problems of metals center around chromium, cobalt, manganese, aluminum, and the platinum group. The United States relies on foreign import for 90% of these materials.(3) Suggested approaches to this crisis are in the development of internal mineral reserves, government stockpiling, and materials conservation and substitution. Of these, the most practical and readily instituted are conservation and substitution. Over the last few years technology has made available many methods to permit use of less critical bulk materials. A major example is in the area of surfacing techniques.

RESOURCE CONSERVATION BY THERMAL SPRAY COATINGS

Modern thermal spray coatings technology offers an immediate, proven solution to critical materails conservation. An enormous amount of critical bulk materails are annually lost through forms of wear and corrosion. Conservation of critical materials lost by these phenomena can be effectively achieved

by shifting from bulk fabrication of high alloy components to lower cost, less scarce base metals combined with surface coatings. Materials conservation through the use of thermal spray coatings allows several major advantages:

1. Scarce materials are limited to the surface.
2. Coating thickness can be designed with regard to the service life required.
3. Coatings are applied to the surface in areas only where needed.
4. Worn components can be restored by coatings to original dimension.
5. Coatings allow downtime to be cut relative to procuring new parts.
6. Maintenance costs are reduced due to greatly prolonged part service life.

Thermal Spray Methods

Of the available modern surfacing methods, the thermal spray process is by far the most versatile with regard to economics, range of materials, and applications. Thermal spray is a proven process with enormous potential for immediately reducing the need for critical materials and lowering manufacturing and maintenance costs. The thermal spray coating process permits rapid application of high performance materials from a few mils in thickness to over one inch on parts with complex geometries. The process requires minimum base metal preparation, can be applied in the field, and is a low temperature method in constrast to techniques such as weld overlay.

All thermal spray processes rely on three basic mehcanisms: heating a coating material to a molten or plastic state, propulsion of the material, and impact of the material onto a workpiece resulting in rapid solidification. The coatings are subsequently machined or ground using conventional equipment or in some cases can be used in the as-coated condition. Five principle thermal spray systems are commercially available: combustion wire process, combustion powder

process, plasma deposition, detonation, and the arc wire process. System selection is determined by desired coating materials, coating performance and overall economics. Each system readily lends itself to field applications with the exception of the detonation process which is restricted to complex laboratory applications.

Combustion Wire Metallizing

The combustion wire process is the oldest of the thermal spray coating methods and among the lowest in capital investment. The process utilizes an oxygen/fuel gas flame as a heating source and coating material in wire form. During operation the wire is drawn into the flame by drive rolls that are powered by an adjustable air turbine. The tip of the wire is melted as it enters the flame and is both atomized into particles by a jet of compressed air and propelled to the workpiece. A variation of this process utilizes spray material as ceramic rods for oxide coatings but for the most part this method has been replaced by the combustion powder and plasma spray processes. Spray rates for the combustion wire process range from 5 to 120 lbs/hr and are dictated by the melting point of the material and the choice of fuel gas. The wire spray gun is most commonly used as a hand held device for on-site application although an electric motor driven gun is recommended for fixed mounted use in high volume, repetitive production work. The combustion wire process finds wide use in corrosion protection of large outdoor structures such as bridges and storage tanks and in restoration of dimension to worn machinery components. In general, the wire spray process is a good choice with regard to capital investment, ease of set up, and minimum operator training.

Combustion Powder - Thermospray

Another commonly used thermal spray coating method is the combustion powder spray process. This method greatly extends the range of available coatings and subsequent applications relative to the wire process to include oxides, ceramics, cermets, carbides, and hardfacing materials. In this process powdered coating material is fed from a reservoir into a stream of carrier gas. Here the material is both melted and propelled to the workpiece by the flame and no atomizing stream is necessary as in the wire process. Combustion powder guns are the lowest cost thermal spray equipment, easiest to set up and change materials, and offer a wide range of coating materials.

Plasma

Among the most sophisticated and versatile thermal spray methods is the plasma spray system. Temperatures that can be obtained with commercial plasma equipment have been calculated to be greater than 20,000°F and are far above the melting, or even the vaporization point of any know material. Decomposition of materials during spraying is avoided since very high gas velocities are produced by the plasma and therefore result in extremely short residence time in the thermal environment. Additional advantages of the plasma process is that it provides a controlled atmosphere for melting and transport of the coating material thus minimizing oxidation and the high gas velocities give rise to coatings of near theoretical density. The plasma gun operates on the principle of raising the energy state of a gas by passing it through an electric arc. The release of energy in returning the gas to its ground state results in exceedingly high temperatures. A gas such as nitrogen enters a direct current arc between a tungsten cathode and a copper anode that makes up the nozzle. Both components are cooled by a constant flow of water through internal passages. Here the nitrogen

gas first dissociates into two atoms followed by ionization releasing free electrons. It is this mixed region that is known as plasma. The atomic components recombine outside the electric arc and release their energy as heat and light. At this point powdered coating material suspended in a carrier gas is injected into the plasma and is subsequently melted and propelled at high velocity to the workpiece. In practice, a small amount of a secondary gas such as hydrogen or helium is mixed with the primary gas such as nitrogen or argon to increase operating voltage and thermal energy. The plasma system is capable of producing exit gas velocities of more than 10,000 feet per second and propelling powder particles at velocities above 2,000 feet per second. These conditions give rise to high density coatings and coating bond strength adhesion to steel exceeding 10,000 pounds per square inch in the case of tungsten carbide/cobalt coating material. This coating bond strength is greater than can be measured with the standard ASTM C-633 test method. The plasma spray process is a well developed method offering versatility and control for the deposition of almost any powdered material ranging from metals, ceramics, and even polymer materials. As with other thermal spray processes, the choice of gases, power levels, and other variations of the plasma system have been carefully established by the manufacturer to produce the highest quality coatings and best economics.

Vacuum Plasma

Plasma spraying is conducted in air for most applications, however, the need for ultra high performance coatings of high purity has lead to plasma spraying within a low pressure, inert environment vacuum chamber. Under low pressure, the configuration of the jet emerging from the plasma nozzle is drastically different in character from that obtained under atmospheric pressure. It is much longer and the turbulence at the jet

boundary is considerably lower. The extended plasma in an inert environment provides:

1. A longer heating zone, permitting increased dwell time for efficient particle melting.
2. High plasma temperature well down stream of the nozzle as a result of reduced turbulence which minimizes cooling and mixing with the surrounding inert gas.
3. Increased spray pattern width since the nozzle to workpiece distance is increased.
4. Greater tolerance to changes in spray distance.

The coating advantages by spraying in a low pressure, inert atmosphere environment can be categorized as follows:

1. High coating adhesion due to improved interface conditions such as high preheat and operating temperatures without detrimental surface oxidation.
2. Excellent coating thickness control.
3. Minimum porosity.
4. Improved deposition efficiency of impacting particles.
5. Minimal particle reaction with oxygen during spraying.

The high quality coatings achieved by low pressure plasma spraying are finding immediate application in the coating of turbine blades for jet engines. Initial tests by General Electric's Research and Development Center and Gas Turbine Division has shown that low pressure plasma sprayed coatings will extend turbine blade service to over 40,000 hours in hostile corrosive environments. This method at least triples the life of uncoated blades under such conditions and represents a significant improvement over a currently used coating technique. In another application, jet engine

turbine blade tips damaged from erosive wear are recycled through low pressure plasma spraying by depositing heavy coatings on the damaged surfaces followed by machining to original dimensions. Both applications result in direct conservation of critical materials through the use of thermal sprayed coatings. Precious turbine blade superalloy components can be made to last longer at a cost saving unequaled by other techniques.

The major components of a low pressure plasma spray system are a vacuum tank, vacuum pump, gun and workpiece manipulators, and the normal components of a plasma system. The low pressure plasma system is not restricted to jet turbine applications but is expected to find uses in areas such as piston rings, hard facings for valve seats, and thermal barrier coatings and all areas where a high performance coating is required.

Detonation

Another method of thermal spraying is the detonation process. This process operates by exploding metered amounts of a gas mixture in a gun-like barrel into which powdered material is injected. The spray material is heated to a molten or semimolten state and is transported down the barrel by the shock waves and expansion of the exploding gases. The detonation process produces coatings which function similar to that of plasma spraying. The process is primarily used for deposition of relatively thin (0.010 in.) hard surface coatings of tungsten carbide. However, due to the necessary process controls and high operating noise level, it is restricted to laboratory conditions and simple part geometries.

Electric Arc Process

The last commercial thermal spray system is the electric arc wire process. In this process, two electrically conductive wires are charged

with direct current and an arc is created at the wire tips melting the material. A jet of high velocity compressed air atomizes the molten metal and projects it on to the workpiece. The arc wire spray system is characterized by wide spray profiles, high deposition rates, and strong coating adhesion to steel substrates. Since the process uses only electricity and compressed air, it lends itself to easier moving of equipment from one installation to another and without the need of stocking oxygen and fuel gas supplies. Table I compares the relative cost and other factors of the processes discussed.

Automation

The thermal spray coating process is readily adaptable to automation and each system can be operated from a manual mode for occasional use up to fully automatic operation. Up to five degrees of gun and work motion freedom are achieved with numerical control microprocessors. The state of the art of plasma spraying permits preprogramming of conditions and routines followed by single push-button start-up, finish, and monitoring of conditions during deposition.

THERMAL SPRAY APPLICATIONS

The thermal spray coating process lends itself to coating items of an extremely wide variety of sizes and geometries. Typical part configurations include piston rings, journals, conveyors, shifter forks, extrusion dies, transformer cases, ship hulks, ship tanker compartments, and all the way up to suspension bridges. Each application directly results in critical material conservation through reduction of wear and corrosion and greatly prolonging part service life by allowing use of a high performance coating material over a non-critical base only where required. Overall, applications of the thermal spray process can be categorized into the following areas:

- Wear resistance
- Oxidation resistance
- Corrosion resistance
- Restoration of dimension
- Abradability and clearance control
- Thermal barriers
- Electrical conductivity or resistivity

These applications are served by choices of over 150 different coating materials with different characteristics of toughness, coefficient of friction, hardness, and other properties. These materials can be categorized into the following groups:

- Pure metals
- Metal alloys
- Cermets
- Ceramics and oxides
- Polymers
- Special composite materials

The industries served by thermal sprayed coatings are extremely broad and include: aircraft, railroads, automotive, petroleum, textiles, paper, food, and power generation.

MATERIAL CONSERVATION WITHIN THERMAL SPRAYED COATINGS

Current research in the field of thermal sprayed coatings is taking the direction of further conservation through coating metals substitution and ceramic substitution for metals. A new family of plasma sprayed, ferrous base, powdered composite materials incorporating small amounts of active metals have been introduced to the marketplace. These materials are able to replace high chromium containing coatings in many abrasive wear applications.

Significant research is being conducted in the area of oxide and ceramic coatings. Ceramic coatings offer several attractive properties compared to metals:

1. Manufacturing costs are lower since extraction is not required, thus saving energy.
2. Ceramic materials are very resistance to wear, oxidation, and corrosion relative to metals.
3. Ceramics offer significant weight savings over metals.
4. Ceramics are frequently more available than equivalent high performance metal alloys.

Thermal sprayed coatings of ceramics have found vast applications with regard to wear and oxidation resistance. Plasma applied magnesium zirconate has long been used to protect the superalloy structure of jet engine combustion chambers against oxidation and current research has shown that a thin, insulating layer of thermal sprayed ceramic over gas turbine blades can significantly raise the ceiling of operating gas temperatures and corresponding efficiency.

International Business Machines uses thermal sprayed coatings to protect more than 48 different computer parts from wear. In the IBM 5424 card sorter, a chromium oxide coating extended life from 40,000 operations using metal alloys to over 1.5 million without measurable wear. In another wear application, TRW Corporation has demonstrated up to three times longer life using ceramic coated piston rings relative to hard chromium plated rings in engine tests. Under abrasive wear conditions, ceramics have been shown to outlast high chromium alloys and tungsten carbide-cobalt containing coatings. Current research on thermal sprayed ceramic coatings is focused on enhancement of properties such as toughness, relative ductility, and thermal resistance.

FUTURE CONSERVATION WITH THERMAL SPRAYED COATINGS

The future direction of critical materials conservation on an industrial and national level should rely on two primary factors. First, the establishment of a positive incentive toward the national need for conservation of scarce material resources. Second, an expanding awareness of the potential for techniques such as thermal spray coatings to meet this national need.

Wide industrial use of thermal sprayed coatings should be encouraged through the following methods:

1. Shift from critical bulk materials to coatings applied over non-critical metals.
2. Expand the use of coatings in OEM areas.
3. Promote salvage of critical material parts through restoration by coatings.

TABLE I

MAJOR THERMAL SPRAY SYSTEMS COMPARISON

METHOD	INITIAL CAPITOL INVESTMENT *	RELATIVE PROCESS COMPLEXITY	COATING MATERIALS CHOICES	RELATIVE PORTABILITY
COMBUSTION WIRE	$ 3 - 5 K	MODERATE	METALS/ALLOYS	HIGH
COMBUSTION POWDER	$ 2 - 9 K	MODERATE	METALS/ALLOYS OXIDES/CERAMICS CERMETS CARBIDES	HIGH
PLASMA	$20 - 100 K	MODERATE; LOW WITH AUTOMATION	METALS/ALLOYS OXIDES/CERAMICS CERMETS CARBIDES/BORIDES POLYMERS	MODERATE
LOW PRESSURE PLASMA	> $200 K	MODERATE	METALS/ALLOYS OXIDES/CERAMICS CERMETS CARBIDES/BORIDES POLYMERS	NONE
DETONATION	COATING SERVICE ONLY; NOT FOR OPEN SALE	HIGH	CARBIDES METALS/ALLOYS	NONE
ARC WIRE	$ 9 - 14 K	LOW	METALS/ALLOYS	HIGH

* APPROXIMATE SYSTEM COSTS.

REFERENCES

(1), (2) R.A. Lula, Effects of Materials Shortages on Stainless Steel Technology, Metal Progress, Oct. 1979, pg. 60

(3) D.E. Fink, Availability of Strategic Materials Debated, Aviation Week and Space Technology, May 5, 1980, pg. 42

OPPORTUNITIES FOR CONSERVATION AND SUBSTITUTION OF CRITICAL METALS UTILIZING RAPID SOLIDIFICATION TECHNOLOGY AND NEAR NET SHAPE PROCESSING

Arden L. Bement Jr.
TRW Inc.

OPPORTUNITIES FOR CONSERVATION AND SUBSTITUTION OF CRITICAL METALS UTILIZING RAPID SOLIDIFICATION TECHNOLOGY AND NEAR NET SHAPE PROCESSING

Arden L. Bement Jr.
Vice President - Technical Resources
TRW Inc.

KEYNOTE TALK

OPPORTUNITIES FOR CONSERVATION AND SUBSTITUTION OF CRITICAL METALS UTILIZING RAPID SOLIDIFICATION TECHNOLOGY AND NEAR NET SHAPE PROCESSING

By Arden L. Bement, Jr.

INTRODUCTION

Good morning ladies and gentlemen! It gives me great pleasure to introduce a session which brings before you a group of distinguished speakers who will describe processing technologies which hold great promise for not only conserving energy and the use of critical metals but also facilitating the design of new alloys with substantially improved properties.

The number of developments in new processing technologies over the past two decades have been unprecedented in history. In most cases these developments were spurred by advances in alloy design and the necessity of removing trace elements, inclusions, and grain boundaries which limit the temperature performance capability of superalloys. Subsequent to the dramatic improvements in the temperature capability of wrought and cast superalloys made possible by vacuum-induction and vacuum-arc melting in the 1950's, the increased macro- and micro-segregation brought about by increases in alloy content in advanced alloy designs soon defined an upper plateau in the further temperature capability achievable with ingot metallurgy. Rapid solidification processing has provided new opportunities to rise above that plateau by promoting increased solid solubility, compositional homogenity and new modes of grain boundary modification.

Other revolutionary processing developments in superalloys have also emerged during this period, to include:

1. The application of directional solidification (or recrystallization) to produce both single crystal and columnar grained γ' percipitation hardened or

eutectic-strengthened γ/γ'-αMo and γ/γ'-TaC turbine blade alloys

2. The application of superplastic forging and hot isostatic pressing to turbine disk alloys

3. The use of vacuum investment casting for cobalt-base vane alloys and directional solidification and oxide dispersion strengthening (ODS) for nickel-base alloys.

The last decade has also seen the increasing use of stepped hot-die forging, isothermal forging and superplastic forging of $\alpha+\beta$ and β titanium alloys for engine fans, compressor blades and disks, and for aircraft structural components. The high response of these alloys to superplastic forming and diffusion bonding has made possible dramatic cost and weight savings (ranging from 30 to 60 percent) and reductions in buy-to-fly ratios to two and less in complex structural shapes. The resulting reductions in machining chips resulting from these near net shape forming technologies now amounts to hundreds of thousands of pounds annually.

Advancements not only in the casting of single-crystal turbine blades but also in the split-mold investment casting, centrifugal casting, ferrous die casting, squeeze casting and isothermal casting of large, complex structures have also been highly notable achievements over the past two decades. Furthermore, the hot isostatic pressing of net-shape cast components to qualify them for applications which would normally require the tensile, fatigue and toughness properties of machined forgings has been an especially dramatic development.

Although many of the inventions in processing technology over the past twenty years have been piloted by superalloys and titanium alloys, because of their high performance requirements and raw material costs, a greatly increased interest in the near net shape and rapid solidification processing of aluminum- and iron-base alloys has developed during the past decade

spurred on by requirements for weight reduction, critical materials substitution, increased temperature performance capability, energy savings, and the opportunities in fabrication and tool design offered by CAD/CAM technology.

Three trends deserve attention as we proceed further into the 1980's:

1. The economic incentives for conserving energy and critical materials will become increasingly stronger stimuli for the development of new processing inventions and know-how.
2. The developments in processing technology will increasingly lead developments in alloy design and will provide opportunities not only for the substitution of critical materials but also for their displacement by improved alloy design (e.g., the displacement of cobalt-base vane alloys with directionally-solidified and oxide-dispersion-strengthened nickel-base alloys). However, the increasing fractions of development costs assigned to the performance qualification and data base generation for new alloys and the decreasing cost fraction attributable to the alloy design, per se, will enforce a higher degree of selectivity on those alloys allowed to proceed to commercial scale-up.
3. The unavailability of capital resources and the impeding effects of inflation on both the introduction of new processing technology and the increase in production capacity needed to keep up with demand may have more of an impact on our critical metals dependence than our current use patterns. As the nation and industry adopt rational procurement policies and introduce stockpile countermeasures, the economic and lead-time criticality of supply

disruptions, and hence the threat of their occurrence, should decline.

The general term "near-net-shape processing" applies to metal solidification processing, wrought metal deformation processing and powder metal consolidation processing. However, the remainder of my comments will focus on rapid solidification processing, since it is the newest of these technologies to emerge.

THE PROMISE OF RAPID SOLIDIFICATION PROCESSING

Rapid solidification processing opens up a new world of alloy systems and microstructures which are not possible in the ingot world. With this technology a broad spectrum of structural forms ranging from amorphous "glassy metals" to highly-refined microcrystalline alloy structures can be produced by a variety of processing techniques. These include splat cooling, roll quenching, melt extraction, gas atomization, ultrasonic atomization, centrifugal atomization, rotating electrode atomization, laser or electron-beam surface glazing as well as others. In order to achieve the beneficial effects of rapid solidification, cooling rates in the range of 10^3-10^{6} ^oC/sec are desirable; however, some benefits are only obtained near the higher end of this range.

In the case of rapidly solidified powders a number of relatively conventional techniques can be used for powder consolidation. These include cold compaction followed by hot pressing; direct hot mechanical pressing, rolling, or extrusion; hot isostatic pressing, and others depending upon the alloy and powder characteristics.

Interest in rapid solidification has increased dramatically throughout the world since the pioneering work of Pol Duwez in 1960[1] in splat quenching from the molten state . Although Duwez and his associates anticipated many of the structure and property potentials for amorphous and microcrystalline alloys

produced by splat cooling, it remained for others to fully appreciate that the benefits of rapid solidification could be achieved in bulk sections through appropriate consolidation techniques.

The general benefits of rapidly solidified alloys are as follows:

1. Substantial extensions in solid solubility can be achieved, and in some instances the extended solubility of one component will promote the solubility of others. This enhanced solubility not only provides greater solid-solution hardening but also promotes a higher volume fraction of precipitates during subsequent aging treatments. It also retains undesirable impurities in solid solution that would degrade grain boundary and interface properties, promotes microstructural stability through the reduced kinetics induced by high melting temperature solutes, and allows the additional solute content for forming more-protective surface scales for corrosion and oxidation resistance.
2. A high degree of homogenity can be achieved, reducing the free energy of the alloy system and contributing to both structural and chemical stability.
3. High levels of microstructural refinement can be achieved to enhance low temperature strength, ductility, fracture toughness, and fatigue life. Furthermore, the stabilization of fine grain structures with highly dispersed precipitates or inert particles can promote superplastic behavior and reduce embrittlement responses in transformed structures.
4. Metastable phases, which would not occur at the low solidification rates of ingot metallurgy, can be formed, and

5. Metallic glasses can be formed which exhibit unusually high fracture strength, corrosion resistance, and wear resistance to include excellent magnetic properties for some metallic glasses.

Since the other presenters in this session will describe alloy developments and near net shape manufacturing technologies in some detail a few examples of important new alloy developments which have the potential of displacing critical metals will suffice.

1. <u>Nickel-base Superalloys</u>

   Pratt & Whitney investigators[2] have developed one of the strongest superalloy compositions to be developed over the last few years containing an enhanced solid solution strengthening of γ' by molybdenum and tungsten. This alloy, containing 6.8 w/o Al, 14.5 w/o Mo, 6.2 w/o W, and 0.6 w/o C, exhibits both an excellent response to diffusion bonding and good compatibility with conventional types of protective coatings. Therefore, it is one of the leading candidate alloys for the radial wafer turbine blade concept under development by Pratt & Whitney Aircraft. This high-solute alloy can only be used in powder form, since severe segregation would occur during conventional ingot casting. Rapid solidification processing offers two general opportunities for backing out cobalt from nickel-base superalloys:

   1. Development of cobalt-free, enhanced-solute superalloys which have greatly enhanced creep and stress-rupture properties, and
   2. The modification of conventional alloys to trade off enhanced properties for reduced cobalt content.

As pointed out by Tien[3] superalloys may not require the present levels of cobalt to deliver acceptable performance. He further points out that the substitution of nickel or other elements for cobalt in superalloys could result in a 10 percent or more reduction in the total US yearly demand for cobalt.

2. <u>Aluminum Alloys</u>

The Air Force Materials Laboratory[4] has had promising success in developing high temperature aluminum alloys by rapid solidification processing which exhibit superior creep strength compared with 2xxx alloys currently in use for high temperature service. If these alloys, based upon the Al-Mn-Co, Al-Fe-Co (alternately Al-Fe-Ni), Al-Fe-Mo, and Al-Fe-Ce systems, prove promising for service at temperatures in the range of 450^{o} to $650^{o}F$ (230^{o} to $340^{o}C$) they could displace titanium and alloy steels for some aircraft structural applications.

3. <u>Iron-base Alloys</u>

Slaughter and Das[5] have investigated iron-aluminum alloys containing TiB_2 as a dispersion strengthening phase to provide a viable substitute for chromium-bearing stainless steels currently used in critical jet engine compressor components.

Preliminary work has shown a 20% weight reduction and a $110^{o}C$ improvement in heat resistance over current ferritic stainless steels.

These studies are continuing in collaboration with Ohio State University to explore the mechanical properties and microstructural characteristics of Fe-Si-Al alloys fabricated from rapidly solidified powder. The expectation is that these alloys could be very attractive replacements for stainless steels and

superalloys for intermediate temperature ($600\text{-}1000^{o}C$), oxidation-resistant applications and that the brittleness normally exhibited by these alloys when prepared by ingot metallurgy can be overcome to acceptable levels with rapid solidification powder metallurgy.

The examples given above are a selected few to illustrate alloy developments currently underway which offer opportunities for direct critical metal substitutions. Equally important are such other developments as the following:

1. The increase in forging capacity and reduction in forging temperatures through improved superplastic response. This would have three major benefits:
   a. increased applications of precision hot-die and isothermal forging for precision net-shape fabrication
   b. use of less strategic, lower-temperature alloys for die materials, and
   c. the shift in forging demand from the 10,000 to 50,000 ton press size range to the 1000 to 5000 ton range, which represents the peak in our national forging capacity
2. Extend the life of high performance ball and roller bearings by improving their corrosion resistance and reducing the size of brittle second phases which limit fatigue life.
3. Explore the formation of amorphous surface layers by laser or electron-beam glazing which would greatly improve the environmental resistance and provide a hard facing for those steels and superalloys which are subjected to elevated temperature erosion-corrosion service.
4. Enhance the properties of alloys containing lesser amounts of critically available alloys in an effort to

meet the performance requirements of alloys containing high contents of strategic elements.

CONSTRAINTS

As in most emerging technologies there are potential drawbacks and cautions which can limit the extent and pace of development and application. A few of these are outlined below:

1. Since the effective cooling rate of the powder particles varies inversely with size, powder-making processes which produce a broad particle size distribution would require sieving to achieve homogeneity in the consolidated product. Some processes, such as centrifugal atomization, produce highly uniform distributions and require less classification.
2. Powder handling operations which employ environments which are not totally inert introduce potential explosion hazards and can contaminate the particle surfaces. Although these contaminants can often be removed by vacuum and electron-beam assisted degassing, the additional handling imposes a cost penalty and can have deleterious effects on the properties of the consolidated product. As a rule future processing flow sheets which provide direct consolidation (such as spray rolling, layerglazing®, etc.) after powder formation in a totally enclosed inert atmosphere will most likely produce the highest quality products and provide major economic advantages.
3. Molten metal which comes in contact with ceramic liners, pouring tuns, and insulating surfaces are likely to carry over foreign inclusion particles into the finished part. This is a serious problem for

highly stressed HIP'd turbine disks which are susceptible to low-cycle fatigue. Current practice is to screen the powders to eliminate those nonmetallic inclusions which can significantly reduce the number of cycles to failure in low-cycle fatigue. Screening at these fine powder sizes (-150 mesh and finer) entails a number of difficulties and could probably be avoided by containerless or cold-hearth (laser-, arc- or electron-beam) melting coupled with the rigorous maintenance of inert processing conditions.

4. Careful attention to gas entrapment during powder processing, especially in superalloys, is required since such entrained gases can give rise to thermally-induced porosity which can serve as fatigue initiation sites at service temperatures.

5. The impedence of boundary migration during directional recrystallization by second-phase particles, low angle boundaries, and stacking faults in rapidly-solidified superalloys is not well understood. Since this process is relied upon to establish columnar grains with a preferred crystallographic anisotropy and grain boundary alignment in blades and vanes, any lack of process control can seriously affect production yields.

6. Finally, the theoretical base for describing nucleation and growth, phase equilibria, heat transfer, and the structural and compositional stability of rapidly solidified alloys is only partially developed and not well proven experimentally. This is an area that will require sustained attention and support.

CLOSING STATEMENT

Since I have focused primarily on rapid solidification powder processing in my keynote remarks, I should mention in closing four important development areas requiring attention for the increased application of near-net-shape wrought metals processing. These are as follows:

1. There is a need for advanced nondestructive evaluation techniques for detecting subcritical size flaws in non-sonic geometries. There are three approaches to this problem that look promising. The first is the automatic, adaptive alignment of the ultrasonic transducer to maintain orthogonality to the surface of the part. The second is the use of higher frequencies and spread-spectrum techniques to suppress unwanted reflections from the free surfaces and grain boundaries. Because of the highly-refined microstructures in rapidly-solidified powder metallurgy products, background noise from internal reflecting and scattering sites is intrinsically low. The third approach is to use a water-coupled, matching part which constructs the sonic geometry for inspection.
2. There is a need for continued attention to lubricant development for hot-die forging and isothermal-forging operations.
3. There is need for improved, interactive, CAD/CAM systems for die design and manufacture for a variety of near-net-shape applications to include hot die forging, extrusion, radial forging, hot ring rolling, shear spinning and various forms of shell and sheet forming.
4. There is a need for processing technology to reclaim critical metal content from electrical chemical machining sludge, grinding swarf, and other forms of

scrap. Even with today's advances in near-net-shape forming technologies, considerable critical metal value is present in these forms of scrap, much of which is exported abroad.

In closing, I am looking forward to the presentations which follow and in identifying with you the action topics for these technologies which are deserving of national attention.

1607A

REFERENCES

1. P. Duwez, R. W. Willens and W. Klement, J. Applied Physics, Vol. 31, p. 1136, 1960.

2. R. E. Anderson, A. R. Cox, T. D. Tillman and E. C. van Reuth, Rapid Solidification Processing Principles and Technologies II, Proceedings Second International Conference on Rapid Solidification Processing, Reston, VA., Claitor's Publishing Div., Baton Rouge, LA, pp. 416-429, 1980.

3. J. K. Tien, T. E. Hawson, G. S. Chen and X. S. Xie, J. Metals, Vol. 32, p. 12, 1980.

4. C. M. Adam and R. G. Bourdeau, Rapid Solidification Processing Principles and Technologies II, Proceedings Second International Conference on Rapid Solidification Processing, Reston, VA, Claitor's Publishing Div., Baton Rouge, LA, pp. 246-259, 1980.

5. E. R. Slaughter and S. K. Das, Rapid Solidification Processing Principles and Technologies II, Proceedings Second International Conference on Rapid Solidification Processing, Reston, VA, Claitor's Publishing Div., Baton Rouge, LA, pp. 354-363, 1980.

1607A

REFERENCES

1. P. Duwez, R. W. Willens and W. Klement, J. Applied Physics, Vol. 31, p. 1136, 1960.

2. R. E. Anderson, A. R. Cox, T. D. Tillman and E. C. van Reuth, Rapid Solidification Processing Principles and Technologies II, Proceedings Second International Conference on Rapid Solidification Processing, Reston, VA., Claitor's Publishing Div., Baton Rouge, LA, pp. 416-429, 1980.

3. J. K. Tien, T. E. Hawson, G. S. Chen and X. S. Xie, J. Metals, Vol. 32, p. 12, 1980.

4. C. M. Adam and R. G. Bourdeau, Rapid Solidification Processing Principles and Technologies II, Proceedings Second International Conference on Rapid Solidification Processing, Reston, VA, Claitor's Publishing Div., Baton Rouge, LA, pp. 246-259, 1980.

5. E. R. Slaughter and S. K. Das, Rapid Solidification Processing Principles and Technologies II, Proceedings Second International Conference on Rapid Solidification Processing, Reston, VA, Claitor's Publishing Div., Baton Rouge, LA, pp. 354-363, 1980.

1607A

POTENTIAL OF RAPID SOLIDIFICATION FOR REDUCTION OF CRITICAL ELEMENT CONTENT OF JET ENGINE COMPONENTS

Joseph Moore and Colin Adam
Pratt & Whitney Aircraft

POTENTIAL OF RAPID SOLIDIFICATION FOR REDUCTION OF CRITICAL ELEMENT CONTENT OF JET ENGINE COMPONENTS

Joseph Moore and Colin Adam
Pratt & Whitney Aircraft
Government Product Division

Good Morning.

My presentation to you today will be to discuss rapid solidification processing as it relates to the reduction of strategically critical elements in the jet engine. The specific technique that I will be speaking to you about is the RSR Powder Metallurgy Process, which is shown in the first chart. The process is one whereby a liquid stream of metal is poured onto a rapidly spinning disk, centrifuged into fine particles, and quenched in a high conductivity helium gas environment. The process causes the ejected metal particles to solidfy at rates of cooling in excess of 100,000 degrees per second, with resulting near perfect chemical homogeneity, closely duplicating the homogeneity of the liquid from which it came. The work that I will be addressing deals with nickel, steel, and aluminum alloys, all of which have application to our jet engine product line.

To provide some perspective as to the characteristics of solidification in the RSR process, I refer to the second figure. In this chart is shown the cooling rate capability of particles varying in diameter form approximately 0.1 micron to 1000 microns.

Shown on the chart is the condition for film heat transfer transfer coefficient equal to infinity, and the condition for the RSR process, for droplets being accelerated from a central source such as a rotary atomizer into the quench media. As can be seen, for the condition $h = \infty$, solidification rates from 10^5 degrees per second and up occur for particles 1000 microns or finer. In the RSR process, the same consideration can be made for particles 100 microns or finer. Our past experience with powder metallurgy alloy, as it was first applied to our F100 engine program (and specifically to superalloy turbine disks), showed that it was feasible to work within the regime of 10 to 100 micron powder particles for consolidification to high quality product, without imposition owing to very fine powder features or to the contamination such as oxygen getering normally associated with talc type materials. Many people have conducted studies in the field of rapid solidification and it is accepted that cooling rates of 10^5 and higher can be considered as the splat range, in which chemical segregation of highly alloyed materials is minimized to the point whereby, on subsequent processing under controlled conditions, it can be essentially

eliminated. The actual device that is being used by the Pratt & Whitney organization is shown in the following chart. It is presently capable of handling up to 300 lbs of metal in a batch mode. The furnance operation is vacuum induction and, initially, the charge of metal is heated under vacuum until a liquid, at which time the device is backfilled with helium gas the turbine activated, and pouring commenced from the melting crucible onto the disk. We initially started the project whereby the helium gas was injected and allowed to dump to atmosphere. The present form of operation is to recirculate the helium in a closed-loop manner thereby providing an all over practicality and a degree of economic utility that heretofore was not achieved. The powder, subsequent to centrifuging and solidification, is collected by means of cyclone separators. Overally, the machine operation relies on three basic elements: 1) state-of-the-art melting which can be converted from vacuum to inert gas melting, 2) high speed turbomachinery for the centrifical atomization and 3) heat transfer based on the local heat profile of the solidifying particles as they are ejected from the atomizer. We have worked with the device since 1976 and the

work that I will refer to from this time on is work that has been sponsored by ARPA, the Advanced Research Projects Agency, in Washington, and the AFWAL Materials Laboratory at Wright-Patterson Air Force Base, Ohio.

The first slide that I would like to show you is that of creep deformation of an RSR developed alloy which contains no critically short elements. It has no chrominum, no tantalum, nor any cobalt, of which to us are elements that need to be addressed from a standpoint of minimizing their use. We found by processing in the RSR mode and allowing the materials to undergo a gradient anneal leading to directional recrystallization that the metal was significantly strengthened in a creep deformation mode far above that possible by our present alloys, in this case designed MAR-M200. The test which is shown was one conducted at 1800^{O}F and 30,000 psi, which is a critical design point for turbine airfoils in military jet engines. What is shown specifically is that the RSR materials with no critical elements, can withstand substantially more time at temperature and load than can our best material of today. It should be noted that our current material contains approximately 12 percent

cobalt and about 9 percent chromium.

On the following slide is shown a more recent development with the same base alloy relative to its endurance capability under conditions of high temperature oxidation. In this case, the base alloy in the previous chart was alloyed with minor additions of hafnium and yttrium in the less than 1 percent range and had a minor of chromium addition of 3 percent. What can be seen is that, whereas the initial base alloy as suggested by endurance in cyclic oxidation was not significantly better than our current alloy, the modification with the minor element additions has increased its resistance to oxidation many times. In fact, in the test shown here at $2100^{O}F$, when measuring a weight loss per unit area factor, there is no discernible evidence that the modified base alloy was degrading in the environment for at least the period of time shown in the chart. This test is on going and the results of more prolonged exposure are continuing to show that minor element additions to the base alloy maintain a high degree of oxidation resistance for this otherwise very strong material.

Our interest in this metal is as an air cooled turbine

airfoil. As shown on the following chart, and in interpreting blade metal temperature capability relative to a parameter of one percent creep in 100 hours which would be considered a design point for air cooled turbine airfoils, one can see that this type of material offers approximately 150^{O}F advantage in temperature capability over our current metals in the stress range critical for blade design (which is noted as blade midspan). This temperature capability increase can be considered in many fashions to the engine designer. It can lead to better performance of the machine itself by allowing the turbine inlet temperature to rise. It can lead to more durability by being able to withstand higher temperatures while not necessarily seeing them in an existing environment. Or, it can lead to less costly fabrication of components by simplifying designs which are presently used for these parts. Our program with ARPA is viewing performance as the principal attribute from this temperature advantage capability. We are presently evaluating an air cooled, airfoil configuration which we designate a radial wafer blade. In this configuration, individual wafers which can be fabricated by consolidating powder and rolling it to sheet

are sectioned and etched with intricate cooling passages. Subsequently, they are joined together, in our case, by diffusion bonding, and the final assembly electrochemically machined to its aerodynamic envelope. Parts to this configuration have been fabricated from the RSR material and have been engine tested in the F100 for short periods of time. The results were positive and suggested that the coupled technology of a radial wafer blade cooling configuration with new materials of this type can offer substantial performance improvements in component capability over todays present materials and methods of fabrication. To date, some 22 components have been fabricated by this scheme and, while still a small number, it suggested that reasonable quality control could be installed during the individual processing steps and lead to a relatively high yield of finished parts in the wafer configuration.

The following chart shows two blades which were engine tested. The parts were instrumented and run in a core engine and, after eight hours of exposure, which included excursions through all of the individual mission cycles of a military tactical fighter engine, the parts showed no degradation

nor did the instrumentation suggest that any difficulties were being experienced during the conduct of test as a result of the material, the configuration or the manufacturing sequence used. As we view the performance gains possible I refer to the following chart. Current technology allows a turbine inlet temperature of approximately 2600^{0}F for the mission cycles we consider in our product line. Using the radial wafer blade, in conjunction with these RSR materials, allows the temperature inlet capability to rise appreciably. For performance, this rise is of paramount importance. Also, importantly, it can also be used as a capability to improve performance to some intermediate step while taking out the balance of benefit in a durability improvement to the individual component itself. In program work to date, this has been confirmed on several occasions and by numerous laboratory tests.

We have taken the technology beyond that of the superalloys and are presently looking at the use of rapidly solidified aluminum alloys to reduce the amount of titanium that we presently consume in our engine while at the same time, getting additional benefits of costs associated with ease of fabrication, ie.,

aluminum vs titanium fabrication and of reduced weight simply by the fact that aluminum weighs less than its titanium counterpart. Our work was directed towards studying iron and molybdenum additions to an aluminum matrix and what we found was the ability to produce micro dispersions of an Al_3Fe type compound which allowed these metals to operate at a higher temperature capability than conventional aluminum alloys.

The following chart depicts this capability. A conventional alloy today has a useful temperature range (from an engine point of view) up to approximately 350°F. The fan operating temperature of our present machines begins at near 350°F and extends to approximately 650°F. In viewing simply the yield strength and ultimate strength of the RSR processed aluminum materials, one can see that the useful yield and tensile strength of the rapidly solidified alloy approaches 650°F when compared to the conventional alloy limit of 350°F. We are studying the characteristics of fatigue of these metals and, in present studies being conducted by our Florida operations, we are showing that the fatigue debit is significantly less than that experienced by conventional aluminum alloys and, in fact, is meeting the goals

that would be required for the use of aluminum in at least stator assemblies such as vanes and cases of advanced military jet engines. The use of these materials would be a direct substitution for titanium in these parts.

In the iron area, we have undertaken investigations dealing with the intermetallic compound Fe_3Al. As I am sure many of you know, the FeAl and Fe_3Al compounds were studied extensively in the late 1950's and the early 1960's because of outstanding features of oxidation resistance, strength and light weight of the metals. In the following slide is shown the actual oxidation degradation of Fe-Al under cyclic conditions at $2000^{o}F$. This particular material was processed by the RSR process and contained a small fraction of titanium diboride dispersed during the rapid solidification and for which purpose I will refer to subsequently. As one can see, the oxidation resistance is outstanding and, in this case, it is compared with a current alloy which we use for combustor operations, HAYNES 188, and also to a chromium containing stainless steel, Type 347. HAYNES 188 is a cobalt base material, Type 347 stainless has approximately 18 percent chromium. The Fe/Al compound

has neither. As I am sure that many of you know, also, the use of the Fe/Al intermetallic compounds has been negated by the fact that the metals are inherently brittle. They are difficult to fabricate and, to a designer, difficult to design with because of extremely poor ductility. The titanium diboride which was dispersed as a fine phase during rapid solidification was found to pin the grain boundaries whereby the materials could be processed under conditions of very fine grain size control; the outcome being a noticable improvement in ductility and an improvement in tensile strength. A nominal 2 percent addition of titanium diboride, added elementally to the melt and allowed to undergo rapid solidification,was found to be approximately optimum for improving the elongation of the material. Our interest in these types of materials is in the combustor of the jet engine. On the following slide is shown the creep rupture characteristic of the Fe_3Al compound and, in this case, it is compared to 310 stainless austenitic steel and 430 stainless ferritic steel. It is evident that the basic composition is at least as strong in stress rupture as the 300 series and while this is considerably less than the presently used

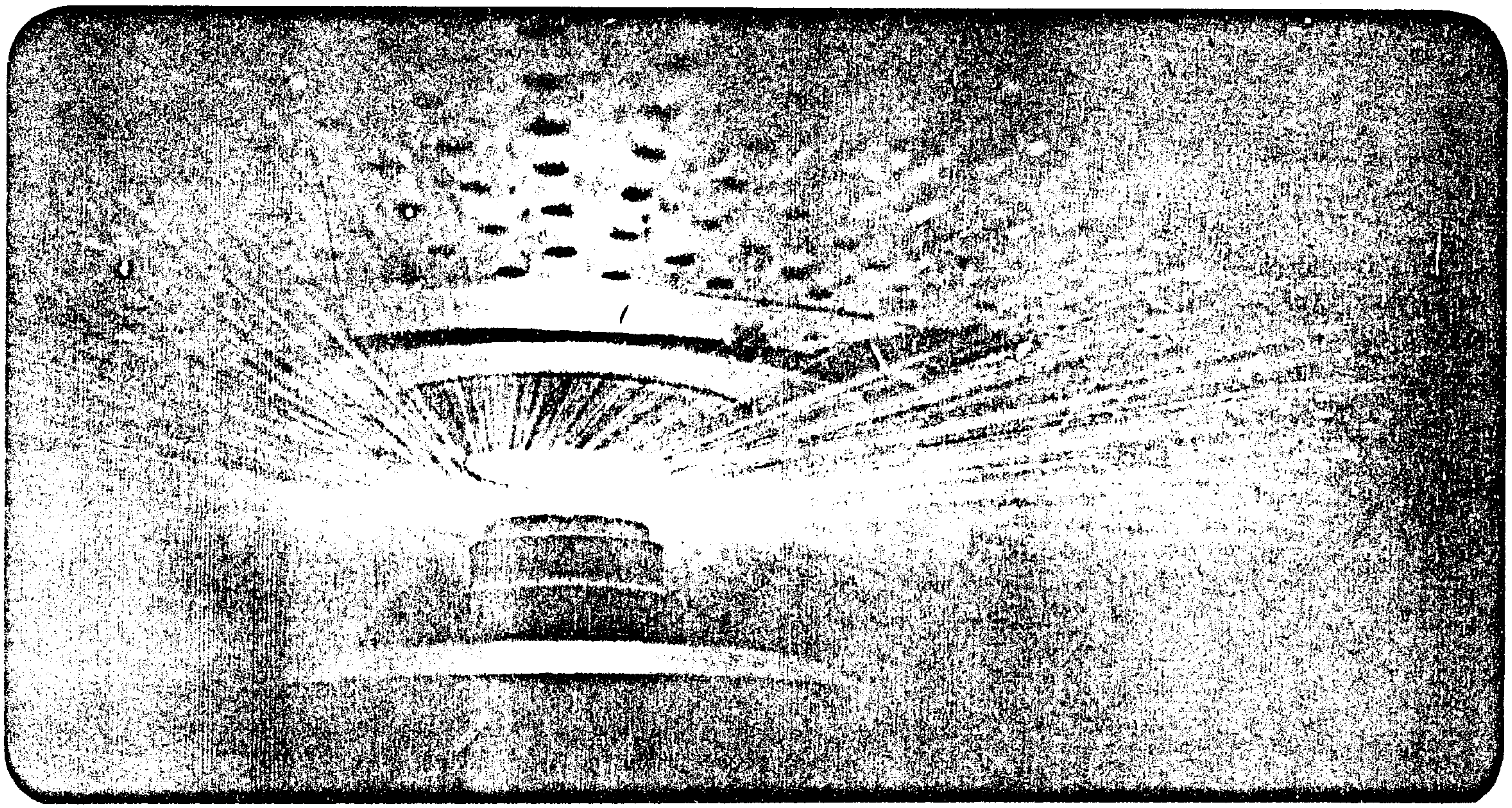
compositions such as a HAYNES 188, there is ample opportunity to make significant improvements in the overall strength of the system by further alloying additions, now that the inherently brittle characteristic of the metal has been eliminated.

Overall, relative to strategic metals, we can view the following slide as an index of risk for various elements that are used in reasonably large quantities in the engine. Those which are most notably high risk are cobalt and tantalum. We use both elements in the hot section of the engine for turbine airfoils, and cobalt for disks. The superalloys we are studying have neither cobalt and minimum, if any, tantalum. Chromium, though presently a low or moderate risk, depending on the political nature, is being addressed by both the superalloys and the steels of the Fe-Al type. In the case of the steels, no chromium is included. In the case of the superalloys, we are looking again at only minor additions of this element. Titanium, though low politically in risk, is a high risk relative to supply/demand. The aluminum alloys that we are looking at are intended to be a direct substitution for presently used titanium.

Finally, I would like to present a example which shows the amount of cobalt presently being used per F100 engine. There is about 900 lbs of cobalt consumed in each build of the F100. In applying current projections with RSR alloys the total amount of cobalt can be reduced approximately 50 percent. With long term projections of rapid solidification alloys, it is reasonable to believe that the overall content of cobalt per F100 engine can be reduced approximately 75 to 85 percent. In closing, then, I would like to say that rapid solidification is a process technique which has opened new doors for improved materials and is allowing the use of elements not in critically short supply to work on our behalf in substituting for these same strategically limited metals.

Thank you.

APPLICATIONS OF RSR TECHNOLOGY



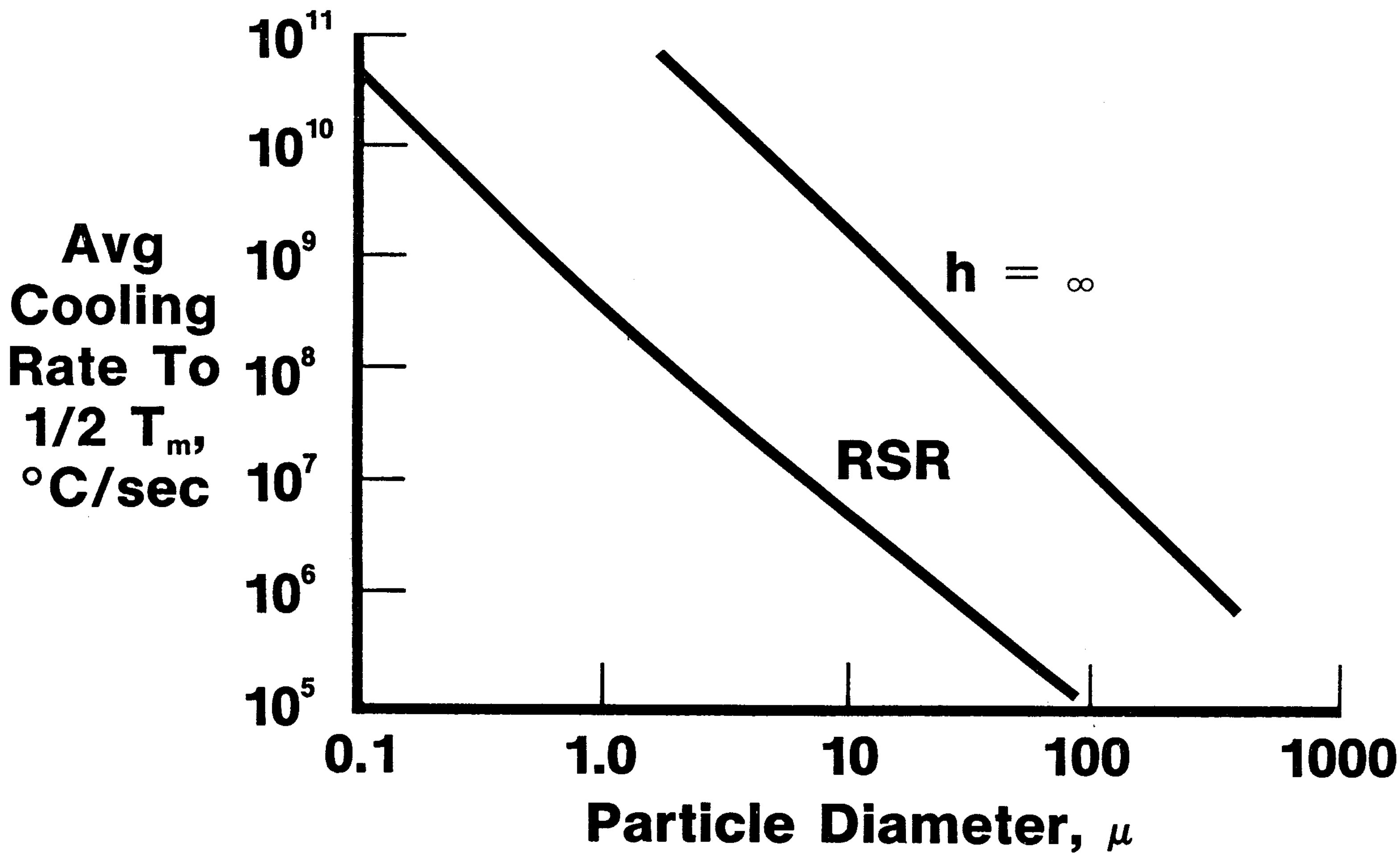
AV 214179
812103
bt1 117

RSR

The RSR process causes metal particles to solidify from molten state under rates of cooling in excess of 100,000°C/sec. The particles have near-perfect chemical homogeneity.

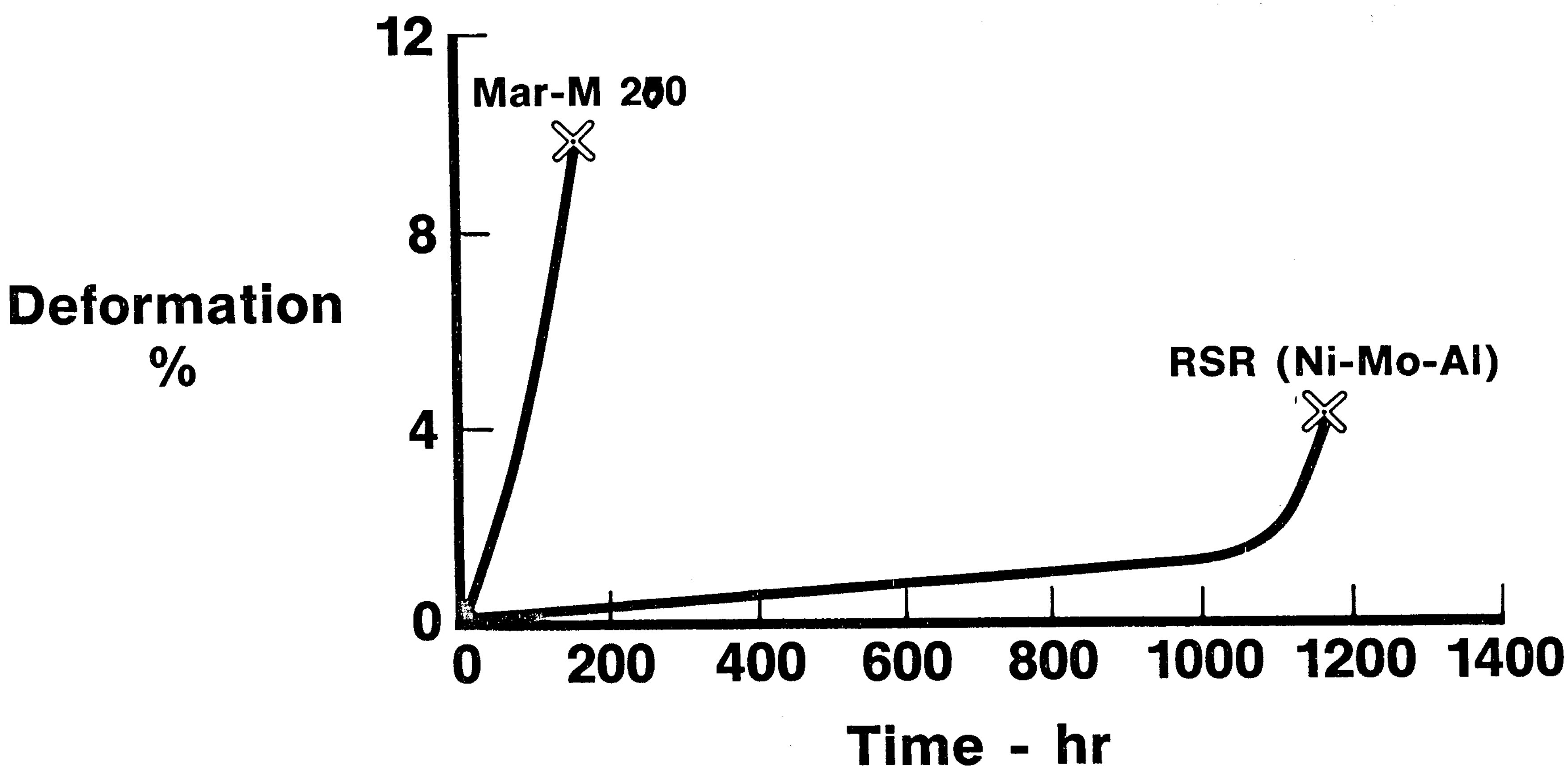
AV 124777
790410
BT2-958

COOLING RATES POSSIBLE IN METAL POWDER



AV 116706A
810605
BET-938

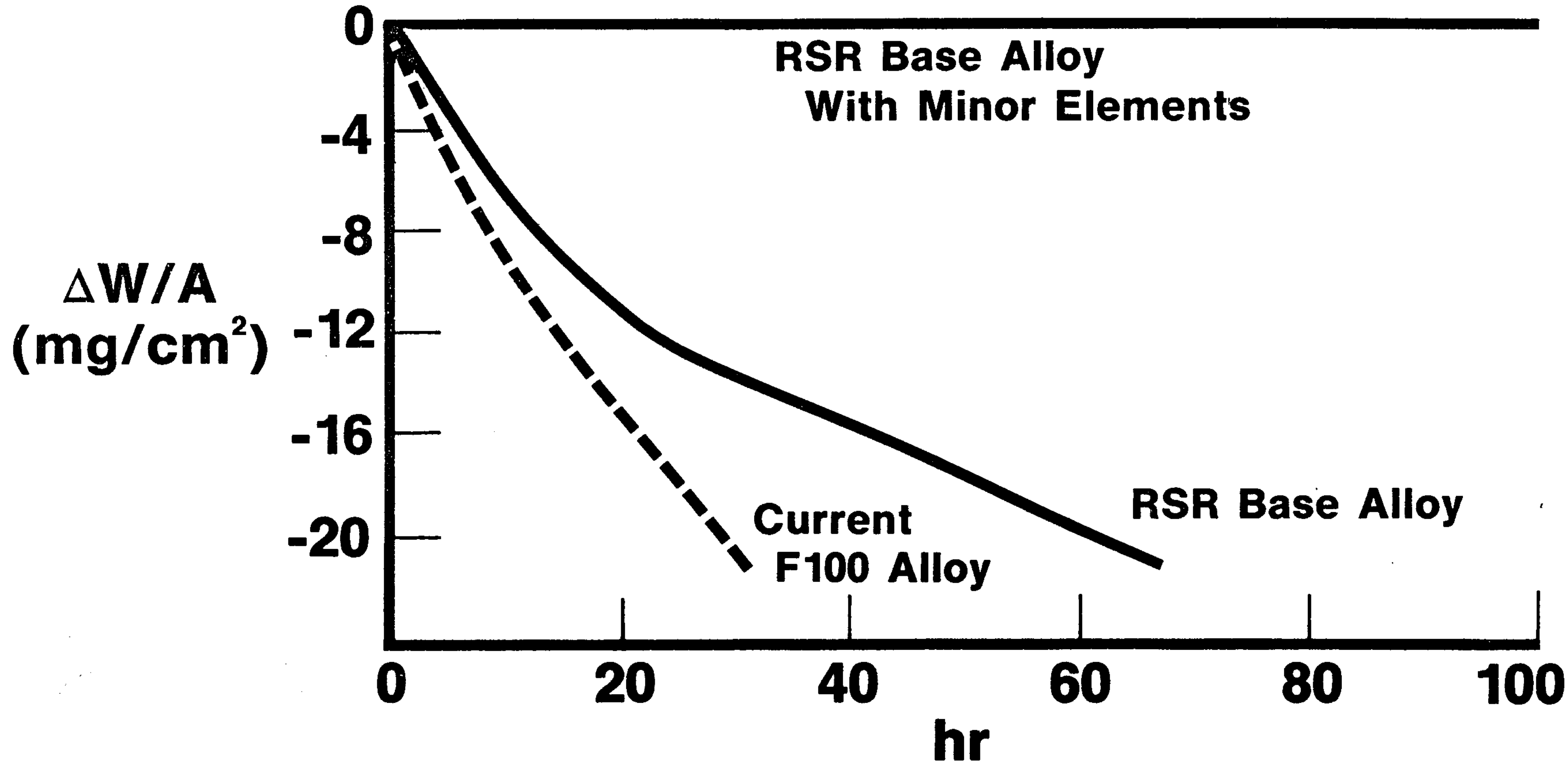
CREEP DEFORMATION OF SUPERALLOYS AT 1800°F AND 30,000 psi



AV 157165A
810605
BET-934

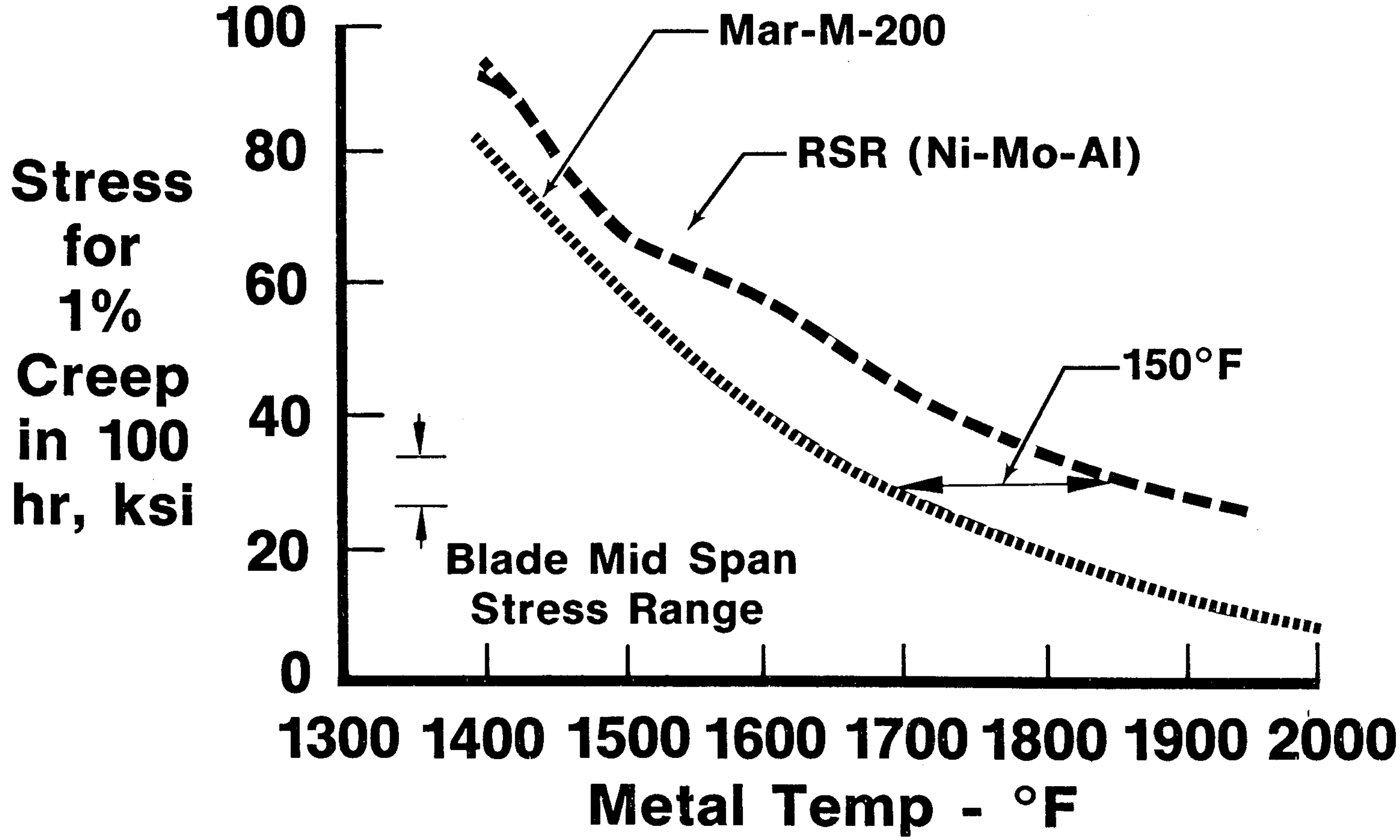
OXIDATION RESISTANCE OF SUPERALLOYS

CYCLIC TESTING AT 2100°F



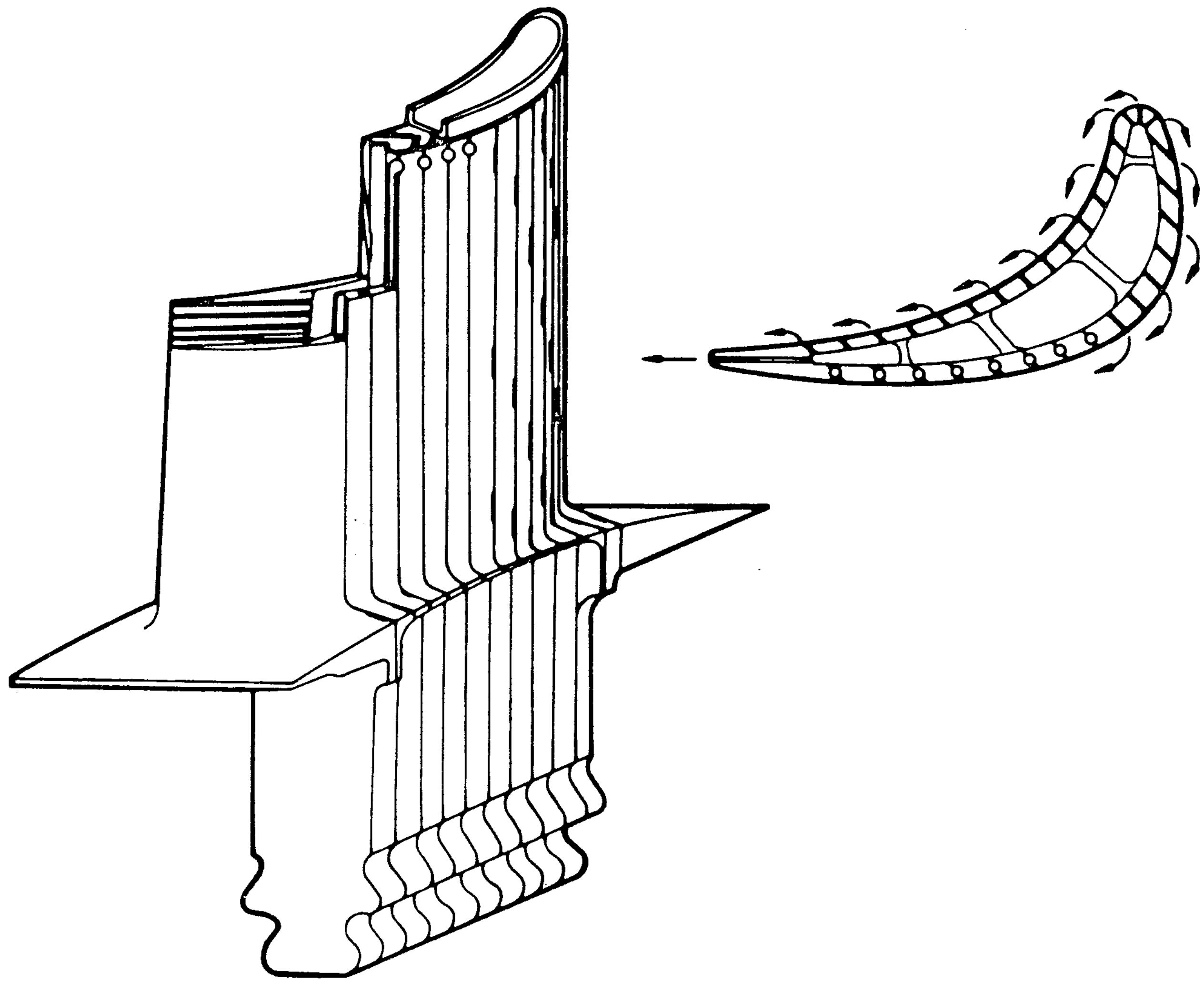
AV 214668
810605
BET-942

CREEP RESISTANCE OF SUPERALLOYS



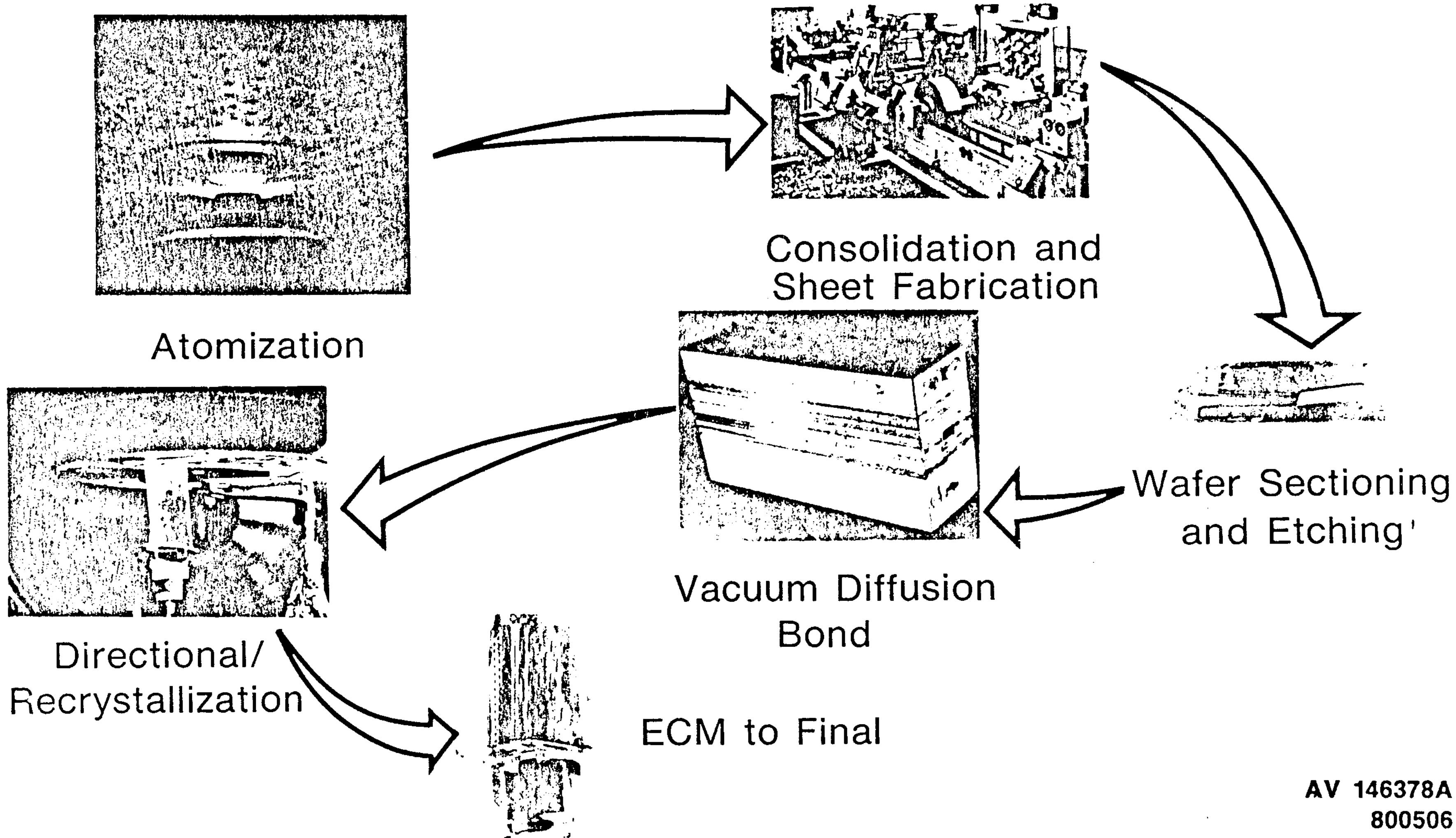
AV 154566A
810605
BET-941

RADIAL WAFER BLADE SCHEMATIC



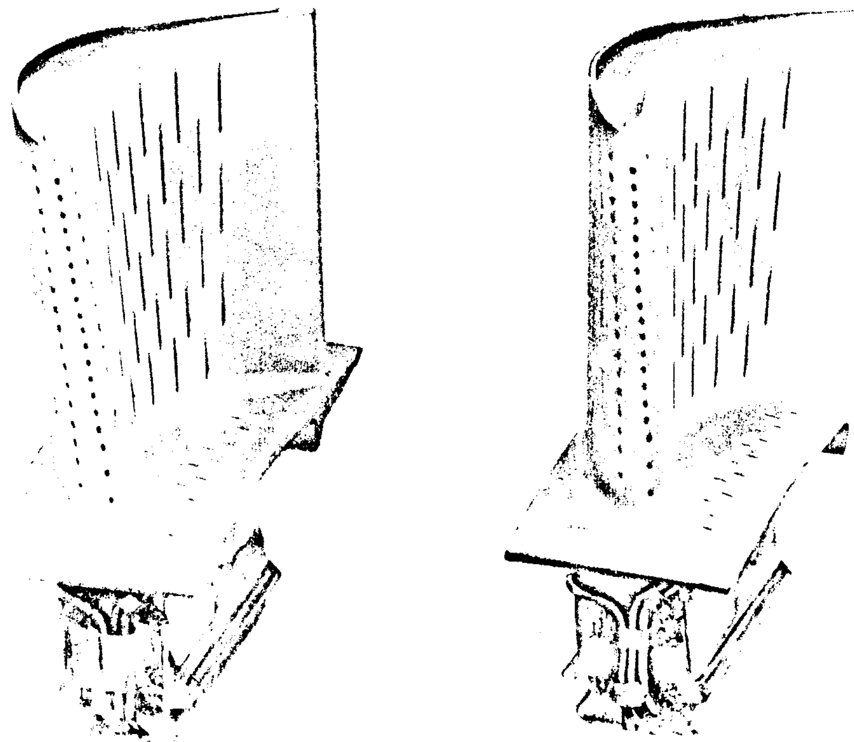
AV 192303
810402
BET-897

MANUFACTURING SEQUENCE FOR RSR RADIAL WAFER BLADE



AV 146378A
800506
gn1 97

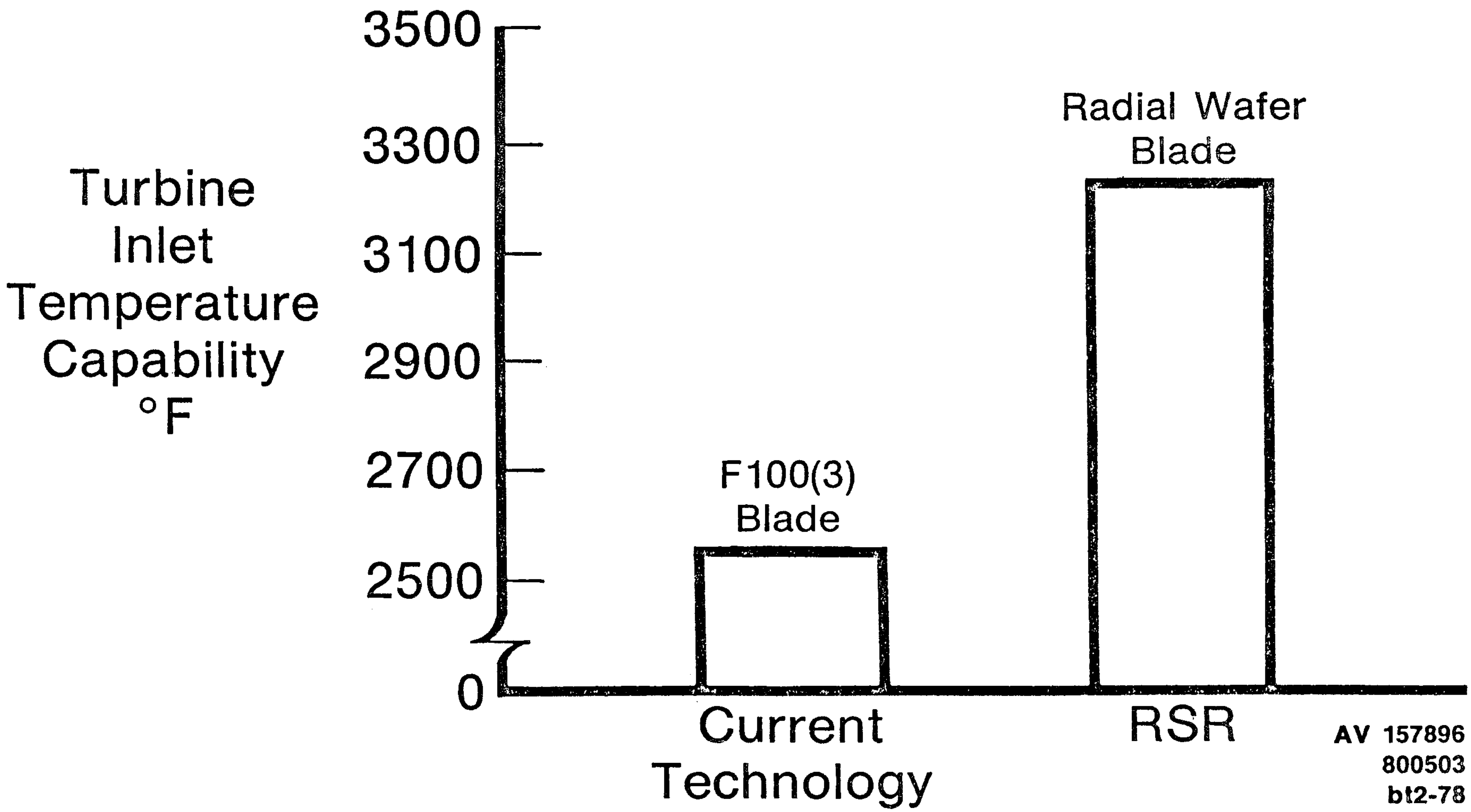
WAFER BLADES AFTER 8 HR OF F100 ENGINE TESTING



AV 219640
810605
BET-939

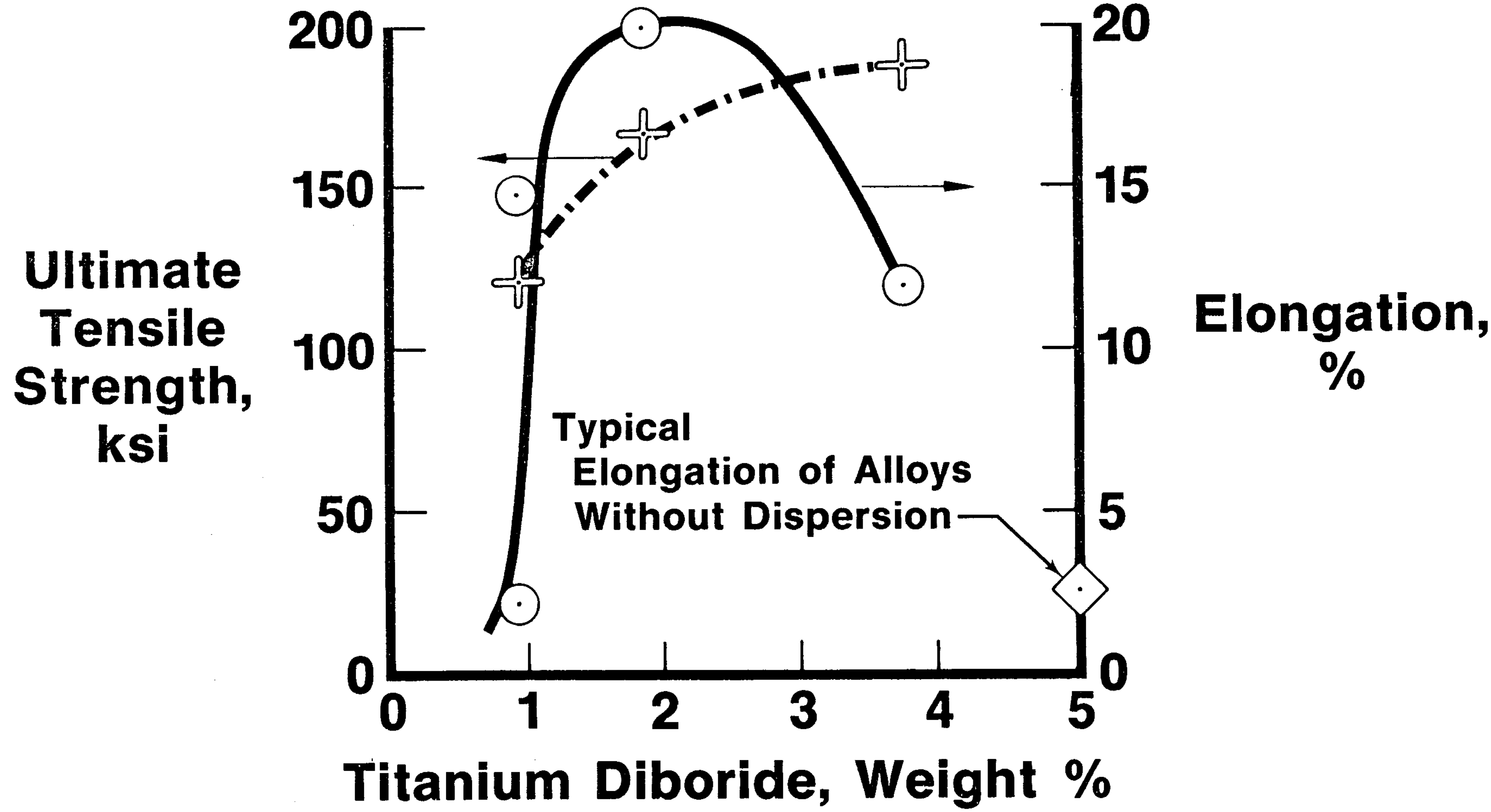
BETTER COOLING AND STRONGER METAL

Allows for Increased Turbine Inlet Temperatures



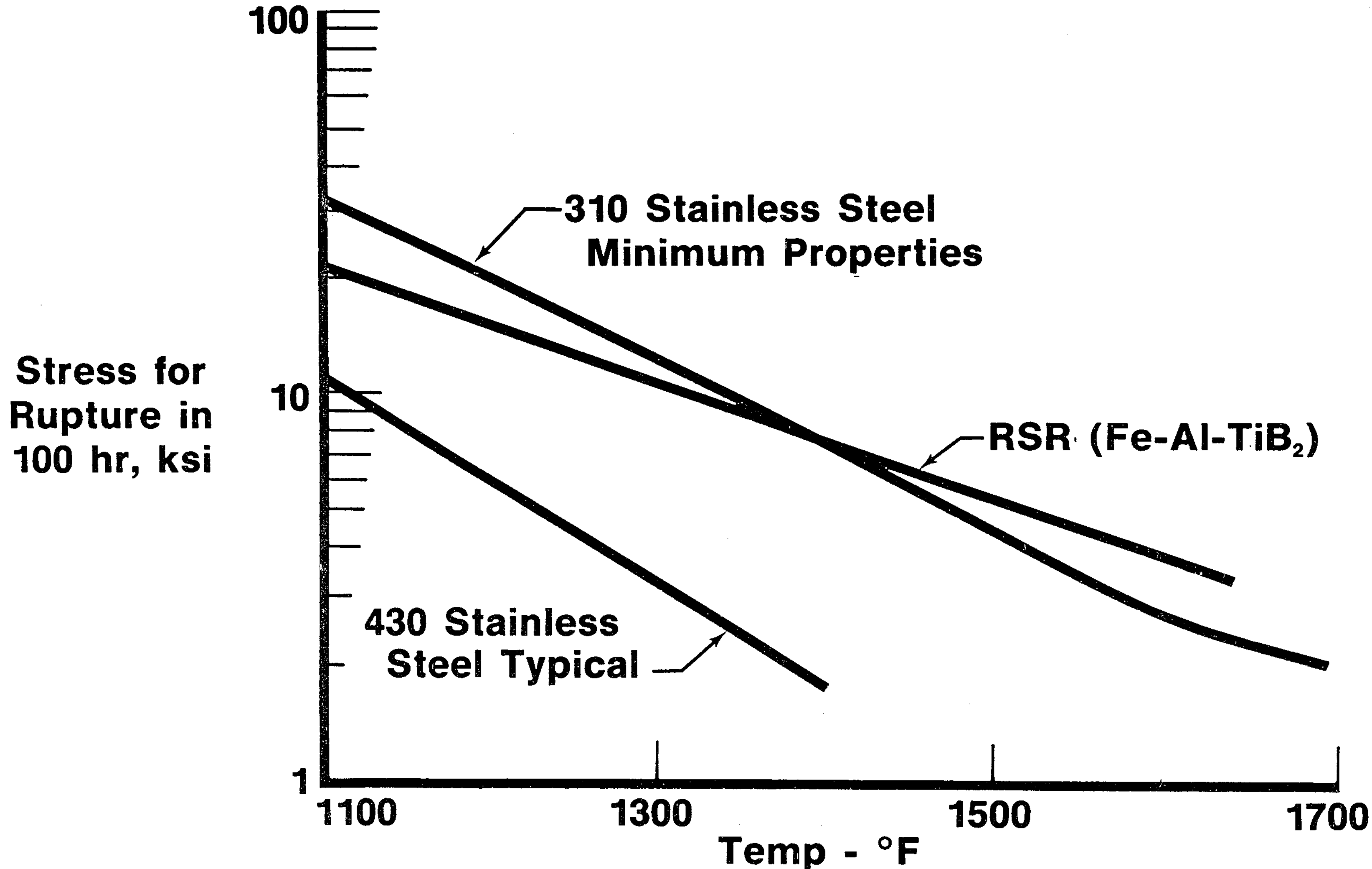
AV 157896
800503
bt2-78

TiB_2 EFFECT OF AMBIENT TENSILE PROPERTIES OF RSR-Fe-Al



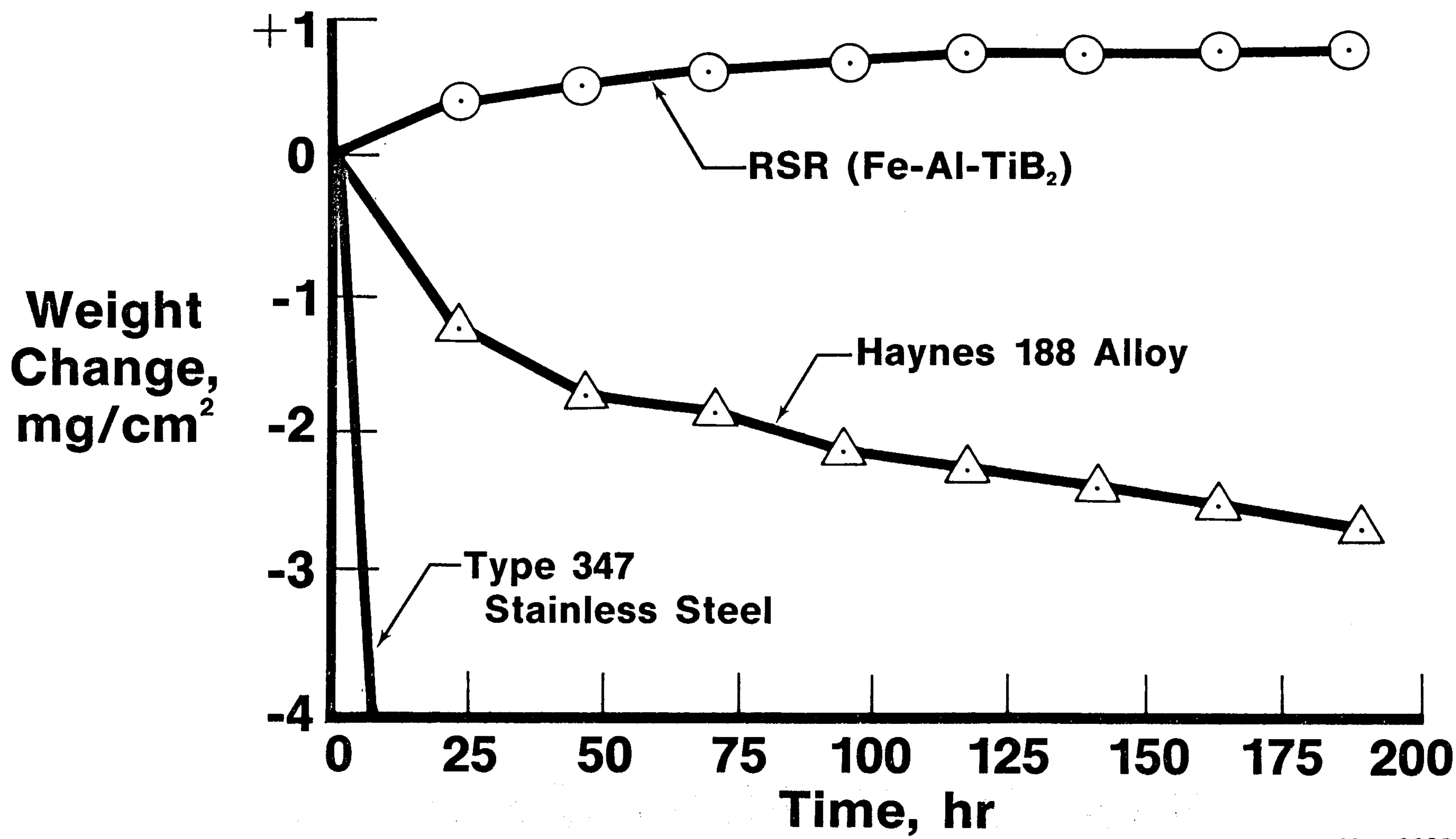
AV 219639
810605
BET-933

CREEP-RUPTURE OF STEELS



AV 158504
810605
BET-940

2000°F CYCLIC OXIDATION RESISTANCE



AV 219638
810605
BET-932

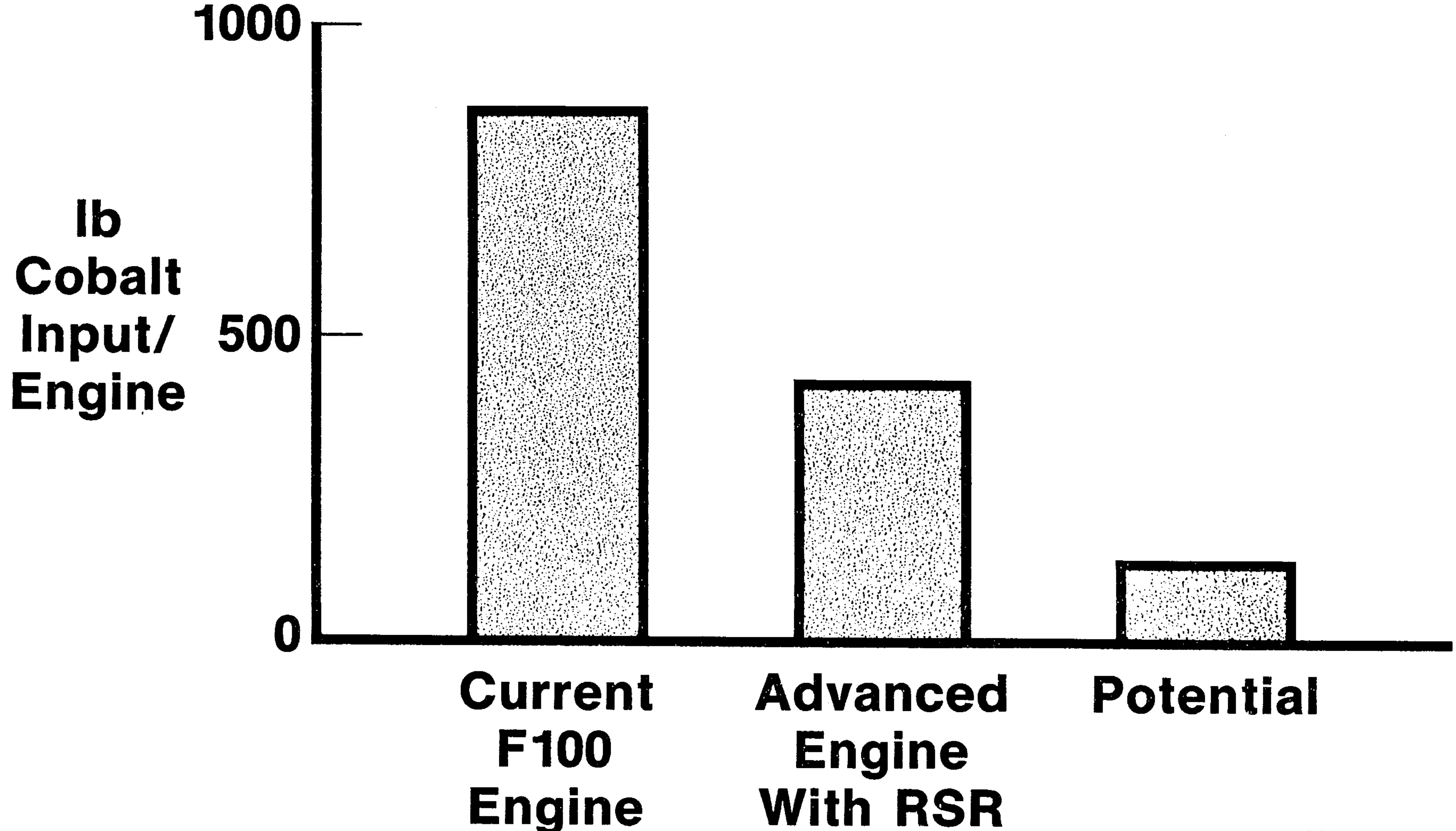
RISK INDEX

STRATEGIC MATERIALS

	Politicial	Supply/Demand
Aluminum	Low	Moderate
Cobalt	High	High
Columbium	Moderate	Moderate
Chromium	Moderate	Low
Nickel	Low	Low
Tantalum	High	High
Titanium	Low	High

AV 168830
810605
BET-946

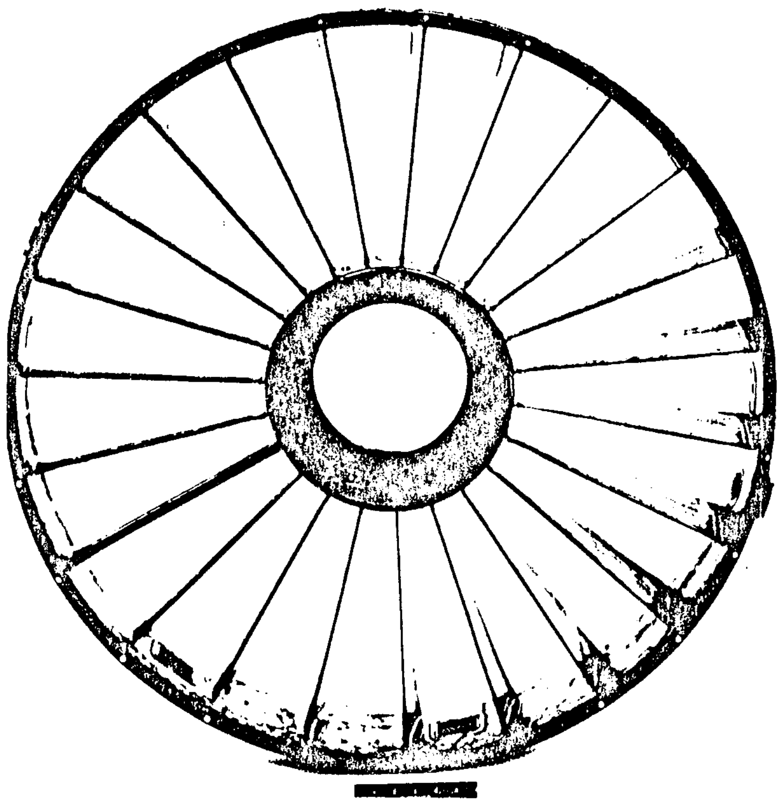
CRITICAL MATERIALS UTILIZATION



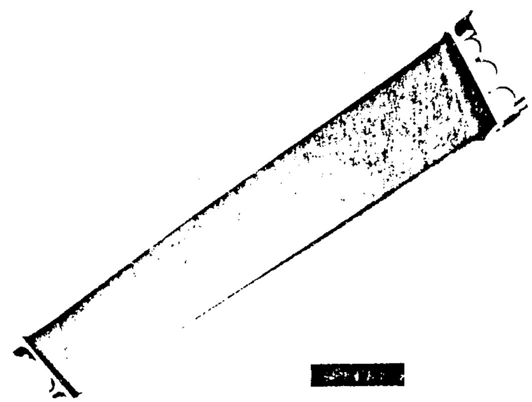
AV 155625A
810605
BET-944

ALUMINUM ALLOY APPLICATIONS

- Reduce titanium usage
- Reduce cost
- Reduce weight



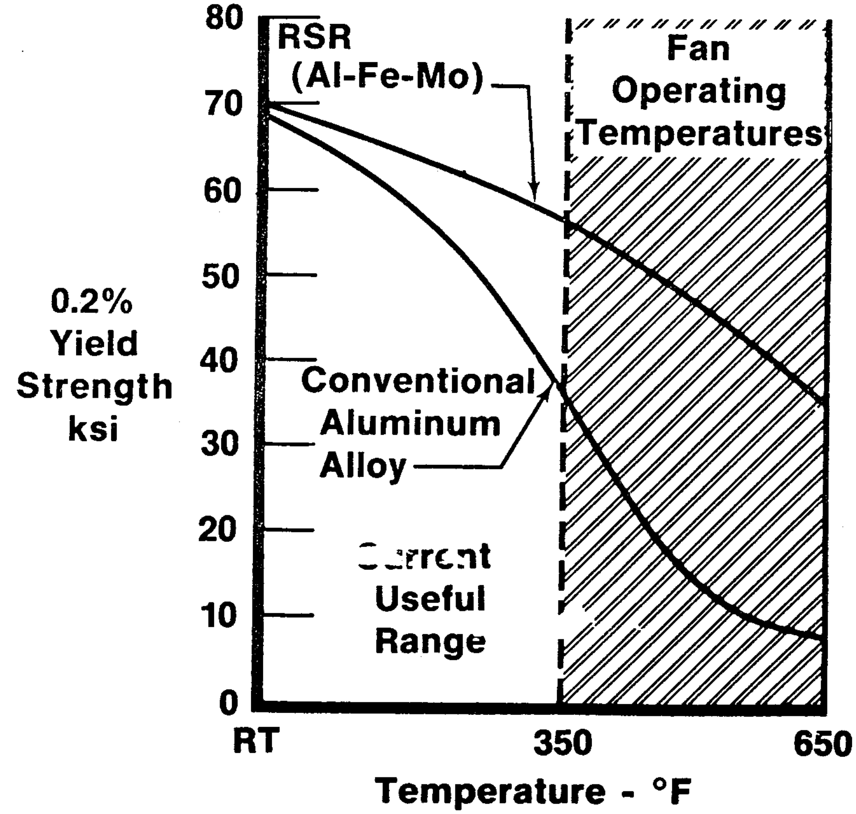
Fan Case

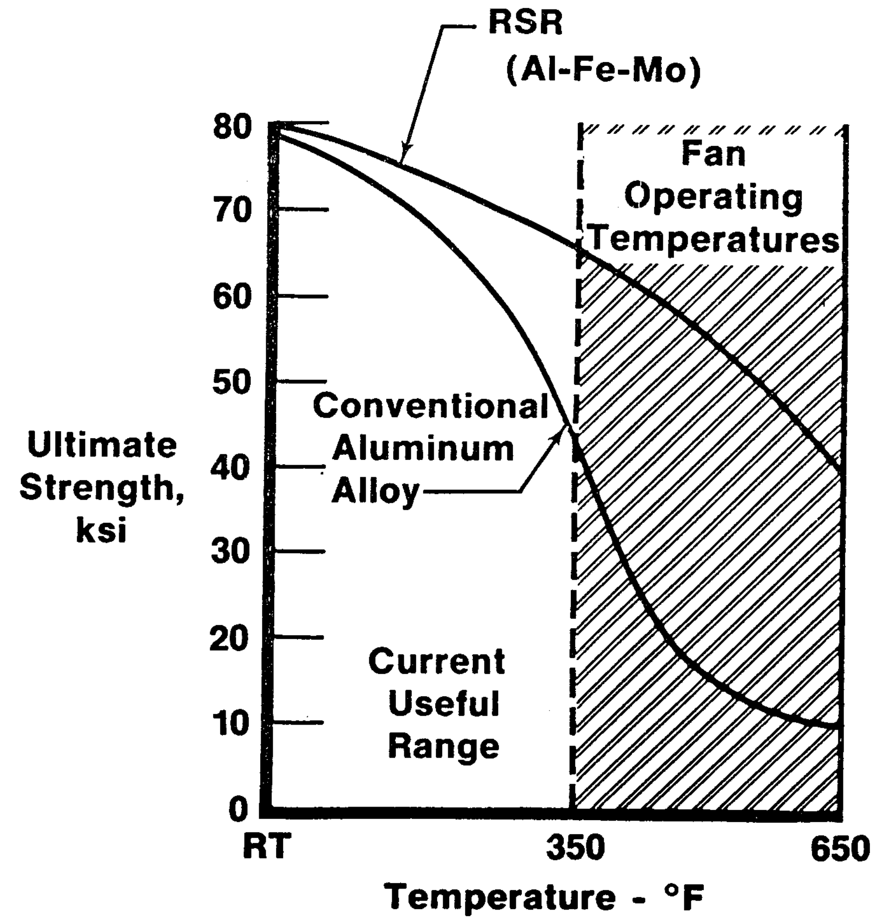


Fan Vane

AV 214184
812303
bt1 113

STRENGTH OF ALUMINUM ALLOYS





AV 214185
810605
BET-936

POTENTIAL OF RAPID SOLIDIFICATION FOR WROUGHT P/M ALUMINUM ALLOYS

Walter S. Cebulak
Aluminum Company of America

WROUGHT P/M ALUMINUM ALLOYS

By combining the advantages of aluminum powder metallurgy, (rapidly solidified particles from molten alloyed aluminum), with special processing techniques, Alcoa is developing a new family of aluminum alloys.

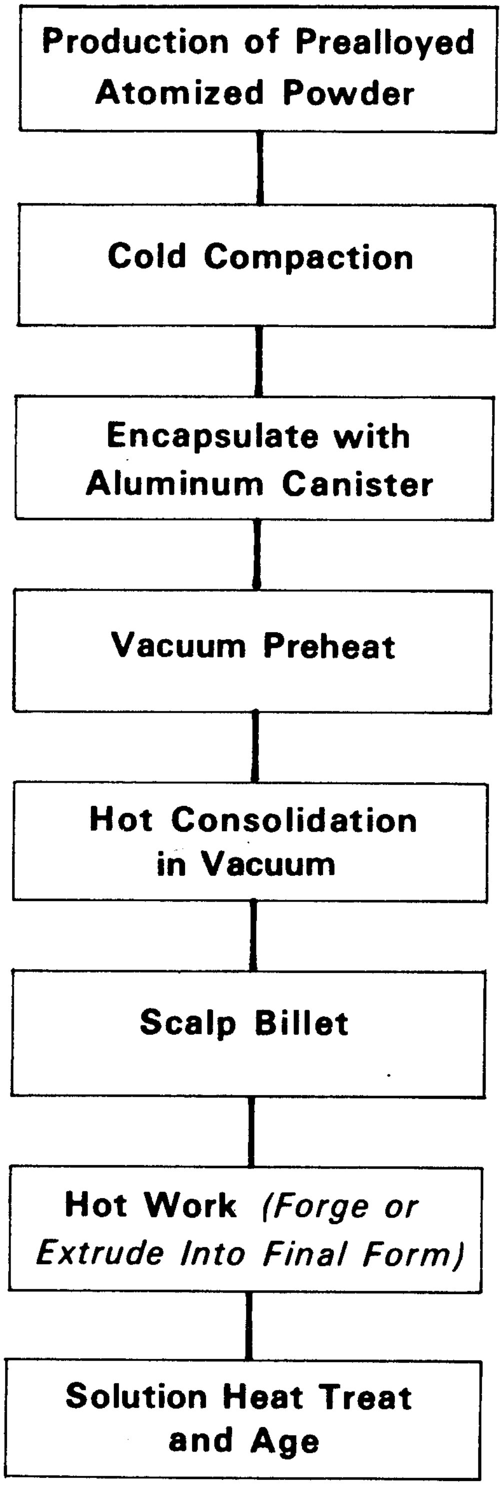
The wrought P/M aluminum alloying process allows a wide range of new compositions to be considered, employing new alloying ingredients and higher percentages of common ingredients normally not permissible with the ingot metallurgy process.

New high-strength alloys produced by the wrought P/M process exhibit fine grained homogeneous structures with excellent fracture toughness and a high resistance to exfoliation and stress corrosion cracking.

Alcoa is producing two wrought P/M aluminum alloys classified in the 7XXX series, initially in billets up to 350 pounds for fabrication into extrusions and forgings.

Designated X7090 and X7091, these alloys have many distinct advantages over similar ingot metallurgy 7XXX series alloys designed for high performance application in aerospace and ordnance structures. They represent the initial step in a program of new process alloy development which promises further improvements in properties and characteristics of aluminum alloys.

Production Sequence Wrought P/M Aluminum Alloy Forgings and Extrusions



To produce wrought P/M alloys, molten prealloyed aluminum is rapidly solidified using atomization technology. This rapid solidification refines the dendritic structure and reduces the size of constituent particles.

The prealloyed powder particles are isostatically compacted into a *green* compact which is encapsulated in an aluminum canister.

The canister and compact are vacuum preheated, then pressed into a billet with 100 percent density.

The canister material is then machined from the P/M billet surface.

Wrought P/M aluminum billets are subsequently fabricated using conventional techniques such as forging, extruding or rolling into sheet and plate.

The solution heat treat and age practices are comparable to those used for ingot metallurgy alloys.

X7090
X7091

Wrought P/M Aluminum Alloys X7090 and X7091

Two wrought P/M alloys are now in commercial production. They were formerly known as MA67 and MA87...then CT90 and CT91, and were recently designated X7090 and X7091 by The Aluminum Association.

X7090 and X7091 are being produced in billets of 110 pounds and a larger, 350 pound size will be available in the near future.

Wrought P/M alloys X7090 and X7091 offer a balanced combination of high strength, fracture toughness, fatigue performance and resistance to stress corrosion cracking and exfoliation.

Nominal Composition
These wrought P/M alloys belong to the 7XXX series of aluminum alloys since zinc is the major constituent. They also contain magnesium, copper and cobalt. (See Table I).

Density and Modulus of Elasticity
Although the density and modulus of elasticity of X7090 and X7091 are almost the same as other 7XXX series alloys produced by ingot metallurgy, (See Table II), their grain structure is much finer and more homogeneous. Other physical properties are similar to 7XXX series alloys produced by ingot metallurgy. (See Table III).

Temper Designations
Extrusions and forgings made from alloys X7090 and X7091 are available for evaluation in various tempers. For forgings these tempers include hot water quenched, compression stress relieved and non stress relieved. (See Table IV).

Properties of Extrusions
The typical longitudinal tensile properties of extruded alloys X7090 and X7091 are shown in Table V. The yield strength of extruded X7090-T7E71 is about 15 percent higher than alloy 7050-T7651X, and X7091-T7E69 shows a 7 percent improvement over 7050-T7651X.

Table V
Typical Tensile Properties For Wrought P/M Alloy Extruded Shapes

		X7090-T7E71	X7091-T7E69	X7091-T7E70
Tensile Strength, ksi (MPa)	L	91 (627)	86 (593)	79 (545)
	LT	86 (593)	80 (552)	75 (517)
Yield Strength, ksi (MPa)	L	85 (586)	79 (545)	72 (496)
	LT	78 (538)	74 (510)	67 (462)
Elongation, %-4D	L	10	12	14
	LT	6	8	10

Note: 0.25 in. (6.4mm) to 1.5 in. (38.1mm) thickness

Chemical Composition Limits For Several High Strength Aluminum P/M And I/M Alloys

	Percent Weight													
												Others		
	Si	Fe	Cu	Mn	Mg	Cr	Zn	Co	O	Ti	Zr	Each	Total	Aluminum
X7090	0.12	0.15	0.6-1.3	—	2.0-3.0	—	7.0-8.4	1.2-1.7	0.20-0.50	—	—	0.05	0.15	Remainder
X7091	0.12	0.15	1.1-1.8	—	2.0-3.0	—	5.6-6.9	0.30-0.55	0.20-0.50	—	—	0.05	0.15	Remainder
I/M Alloys														
7050	0.12	0.15	2.0-2.6	0.10	1.9-2.6	0.04	5.7-6.7	—	—	0.06	0.08-0.15	0.05	0.15	Remainder
7075	0.40	0.50	1.2-2.0	0.30	2.1-2.9	0.18-0.28	5.1-6.1	—	—	0.20	—	0.05	0.15	Remainder
7175	0.15	0.20	1.2-2.0	0.10	2.1-2.9	0.18-0.28	5.1-6.1	—	—	0.10	—	0.05	0.15	Remainder
7178	0.40	0.50	1.6-2.4	0.30	2.4-3.1	0.18-0.35	6.3-7.3	—	—	0.20	—	0.05	0.15	Remainder

Note: Value maximum if range not shown.

Table I

Density and Modulus
Wrought P/M and I/M Alloys

Alloy	Density Lbs./In.^{3} (g/cc)	Modulus Of Elasticity([1]) KSI (MPa) x 10^3
X7090	0.103 (2.850)	10.7 (73.8)
X7091	0.102 (2.823)	10.5 (72.4)
7050	0.102 (2.823)	10.4 (71.7)
7075	0.101 (2.796)	10.4 (71.7)
7178	0.102 (2.823)	10.4 (71.7)

([1]) Average Of Tension And Compression Moduli.

Table II

Typical Physical Properties

Approximate Solidus Temperature

X7090	1018°F (548°C)
X7091	1010°F (543°C)

Specific Heat*

X7090	0.203 Cal/g°C
X7091	0.206 Cal/g°C

Thermal Conductivity*

X7090-T7E71	0.33 Cal/Sec °C/cm
X7091-T7E69	0.36 Cal/Sec °C/cm

Coefficient of Expansion*

68°F - 212°F (20°C - 100°C)

X7090 - 13.2 x 10^{-6} in/in/°F (23.8 x 10^{-6} m/m/°C)

X7091 - 13.1 x 10^{-6} in/in/°F (23.7 x 10^{-6} m/m/°C)

* Calculated Values

Table III

P/M Alloy And Temper Designations

Alloy-Temper	Available Product Forms
X7090-T7E71	Extrusions And Forgings
X7090-T7E75	Die Forgings (Hot Water Quenched)
X7090-T7E80	Hand And Die Forgings (Compression Stress Relieved)
X7091-T7E69	Extrusions And Non-Stress Relieved Forgings
X7091-T7E70	Extrusions And Non-Stress Relieved Forgings
X7091-T7E76	Die Forgings (Hot Water Quenched)
X7091-T7E77	Die Forgings (Hot Water Quenched)
X7091-T7E78	Hand And Die Forgings (Compression Stress Relieved)
X7091-T7E79	Hand And Die Forgings (Compression Stress Relieved)

Notes: Sheet and plate products are currently under development and are not yet available for customer evaluation.

All extrusions stress relieved by stretching.

Table IV

Properties of Die Forgings

The longitudinal yield strength of an X7090-T7E71 forging is about 18 percent higher than a 7175-T736 forging, while X7091-T7E69 is approximately 8 percent higher than 7175-T736.

Table VI
Typical Tensile Properties For
P/M Alloy Die Forgings

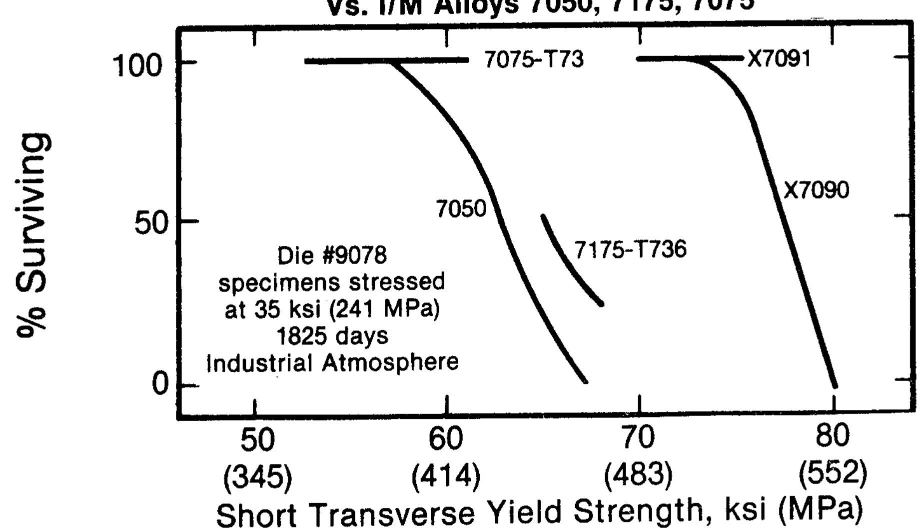
		X7090-T7E71	X7091-T7E69
Tensile Strength, ksi (MPa)	L	89 (614)	84 (579)
	T	84 (579)	79 (545)
Yield Strength, ksi (MPa)	L	84 (579)	77 (531)
	T	79 (545)	72 (496)
Elongation, % - 4D	L	10	13
	T	4	9

Note: $\leq$3.000 In. (76.2mm) Thickness

Resistance to Stress-Corrosion Cracking

Figure 1 shows the percent of short transverse specimens which were stressed at 35 ksi, surviving after 1600 days exposure in an industrial atmosphere. Alloys 7050, X7090 and X7091 were given varying amounts of aging in order to determine their yield strength versus stress-corrosion resistance. Alloys 7075-T73 and 7175-T736 were given the standard heat treatments associated with those tempers and represent the normal strength range obtained using production practices. For a given level of stress-corrosion cracking resistance, as judged by the percent of specimens surviving, the P/M alloys X7090 and X7091 can be aged to yield strengths 10 ksi (69 MPa) to 15 ksi (103 MPa) higher than the best high strength I/M alloys available. The performance shown in Figure 1 was for specimens taken across the parting plane of a die forging known to have a high degree of short transverse grain orientation at the parting plane, thus providing a highly critical test.

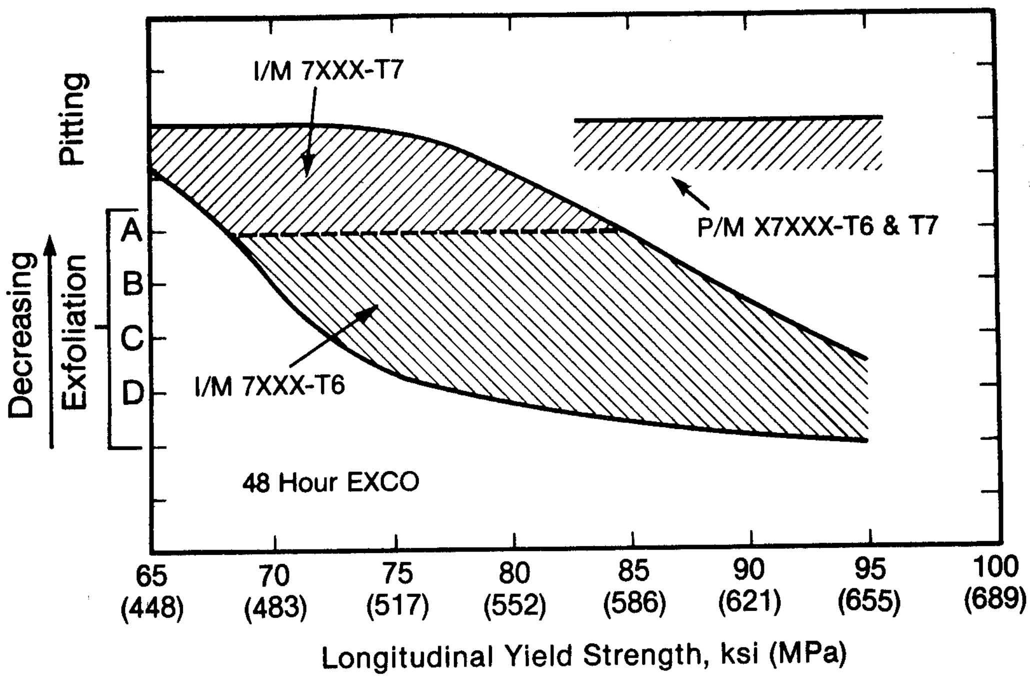
Figure 1
SCC-Strength Capabilities
Thin Web-Flange Die Forgings
P/M Alloy X7090 and X7091
Vs. I/M Alloys 7050, 7175, 7075



Exfoliation Corrosion Resistance
At highest strengths, test evaluations indicate X7090 and X7091 are as resistant to exfoliation as the 7XXX ingot metallurgy alloys in the highest strength tempers developed specifically to resist exfoliation, T76.

The graph illustrates the relationship of strength and exfoliation resistance of I/M and P/M series alloy extrusions in the 48-hour EXCO test. In order to place the ingot metallurgy 7XXX alloys in the "pitting" classification, the alloys require aging to the T7 type temper.

Figure 2
Strength - Exfoliation
I/M Vs. P/M 7XXX Extrusions

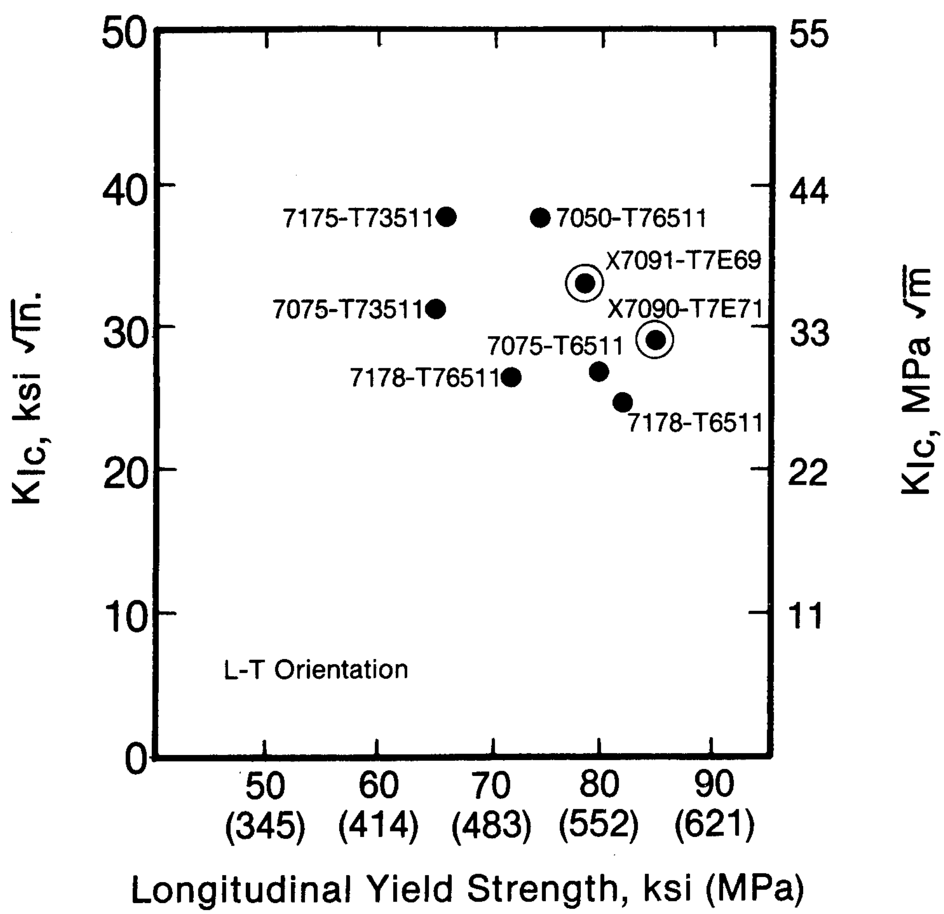


Atmospheric Corrosion
Atmospheric exposure tests at the Alcoa Technical Center near Pittsburgh and Point Judith, RI indicate corrosion of X7090 and X7091 is uniform and non-directional.

Fracture Toughness
Initial testing of the strength-toughness relationships of the new P/M alloys indicate their superiority to many of the 7XXX series I/M alloys. Data points approaching the upper right corner of the graph are preferred.

Alloy X7091 in temper T7E70 (not shown on graph) has high toughness, but valid data have not been accumulated in the L-T orientation. In the T-L orientation, measurements of 43 ksi $\sqrt{in.}$ have been recorded in material with 67 ksi longitudinal yield strength.

Figure 3
Typical Fracture Toughness Vs. Yield Strength
High Strength Aluminum Alloy Extruded Shapes,
0.25 in. (6.4mm) to 1.50 in. (38.1mm) Thickness



Fatigue Strength

Notched axial fatigue strengths of X7090 and X7091 extrusions are 35 to 40 percent better than alloy 7050 and 7075 at 10^6 and greater cycles. A similar advantage is indicated over alloy 2024.

Figure 4
Notched Axial Fatigue Strength Of P/M Alloys X7090 and X7091 Extrusions VS. I/M Alloys 7050 and 7075 Products

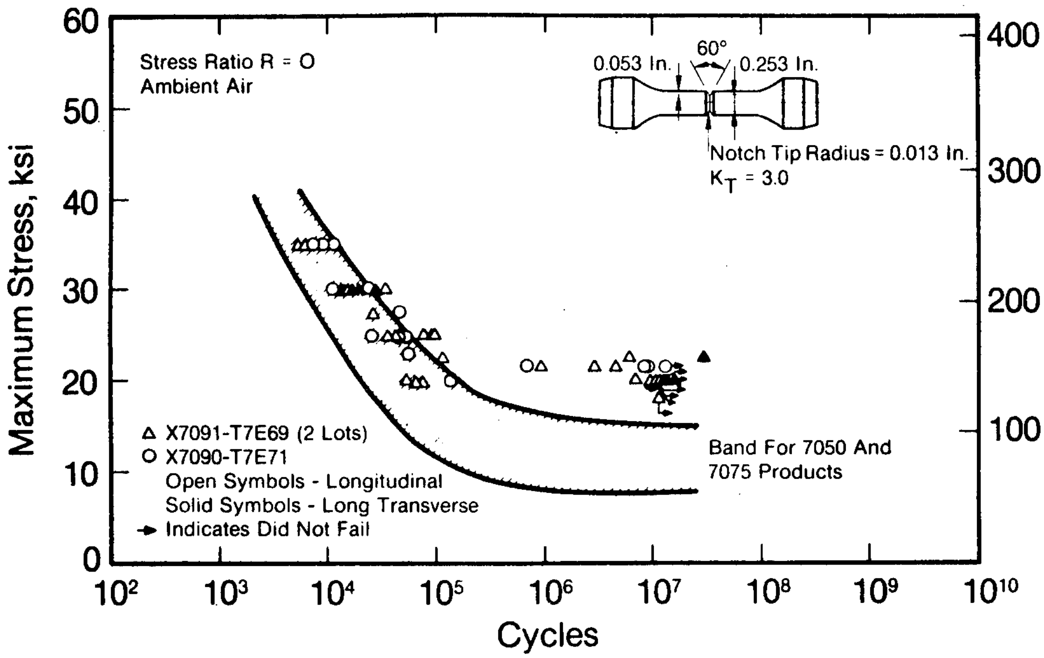
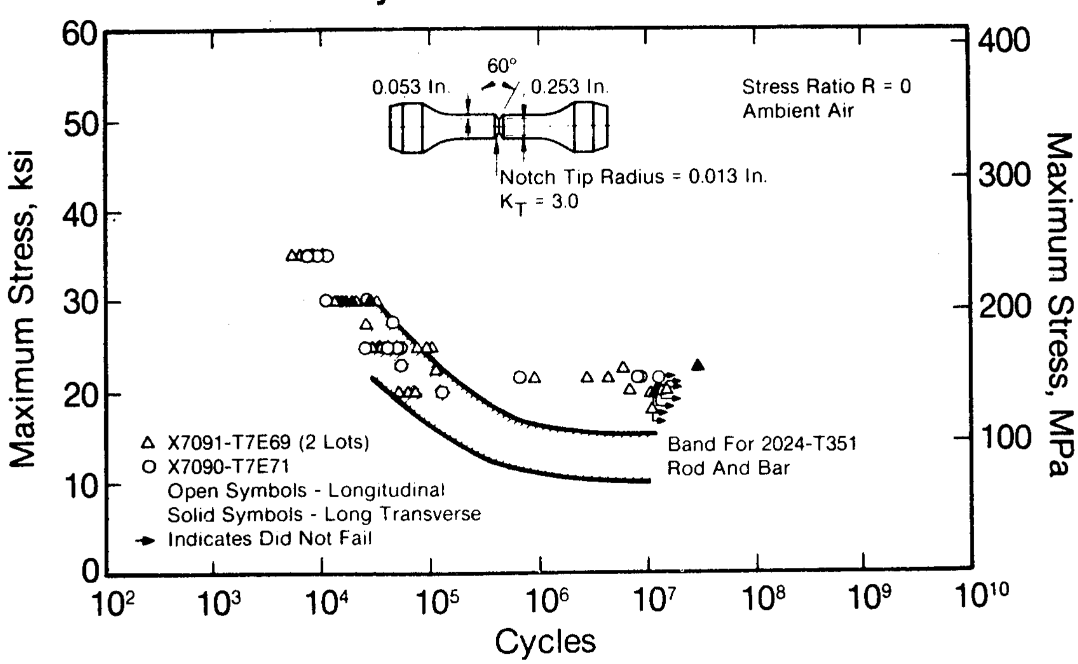


Figure 5
Notched Axial Fatigue Strength Of P/M Alloys X7090 and X7091 Extrusions Vs. I/M Alloy 2024-T351 Rod and Bar



Wrought P/M Alloy and Process Development

Since the early 1960's, scientists and engineers at Alcoa's Technical Center have been developing wrought P/M alloys and the technology needed to produce them in commercial quantities. This developmental work has included evaluations of more than 400 experimental compositions and temper variations.

Alcoa has invested considerable financial and human resources into a number of research projects. Many of these projects were supported by Federal agencies. Such support, instrumental to our progress in the past, is continuing.

Each government funded project has led either to the development of a new alloy with an optimum combination of properties or to improved understanding of the production process.

Nearly half of the projects involved the participation of major aerospace companies. AFWAL is considering the sponsorship of multi-million dollar projects to develop alloys with new combinations of strength, elastic modulus and structural integrity at elevated temperatures.

Government Funded P/M Programs
Alcoa R&D Laboratories

Subject	Contract Number	Government Agency	Other Participants
Precision Aluminum Alloy Powder Metallurgy Structural Components	F33615-77-C-5129	AFWAL	GD/Ft. Worth Lockheed-Burbank Boeing Vertol
Elevated Temperature P/M Alloys	F33615-77-C-5086	AFWAL	—
Fundamentals of Compaction Processes for Rapidly Quenched, Prealloyed Metal Powders	F33615-79-C-5037	AFWAL	—
Optimization of Fatigue Resistant P/M Alloys	F33615-77-C-5174	AFWAL	—
Advanced Aluminum Alloys from Rapidly Solidified Powders for Aerospace Structural Applications	F33615-77-C-5203	AFWAL DARPA	Lockheed- Palo Alto Labs
Advanced Aluminum P/M Alloys for SCAR (Supersonic Cruise Aircraft Research)	NASI-14625	NASA	Lockheed-Burbank
Production and Rolling of Al-Lithium P/M Alloys	DAAK 10-78-C-0410	ARRADCOM	—
Thermomechanical Processing of ARRADCOM Billets	DAAK 10-78-C-0255	ARRADCOM	—
P/M Mill Product Process Optimization	DAAK 10-79-C-0193	ARRADCOM	—
Direct Vacuum Extrusion of High Strength P/M Alloys	F33615-79-C-5053	AFWAL	Boeing McDonnell-Douglas
Cobalt free high strength aluminum P/M alloy	F33615-80-C-5098	AFWAL	Boeing
Alloys With Increased Elastic Modulus	Proposal	AFWAL	
Structural Elevated Temperature Alloys	Proposal	AFWAL	

Goals of Alcoa's Wrought P/M Alloy Program

1. To develop and evaluate improved alloys with the variety and combination of properties which are realistically attainable.

2. To evaluate present production operations at Alcoa's facility and to expand production capacity in both billet size and total tonnage.

3. To obtain joint participation between Alcoa, commercial aerospace companies and government agencies. This participation is to include testing, evaluation and service trials of available products. This will enable feedback on cost effectiveness which is essential in defining the required future production capacity.

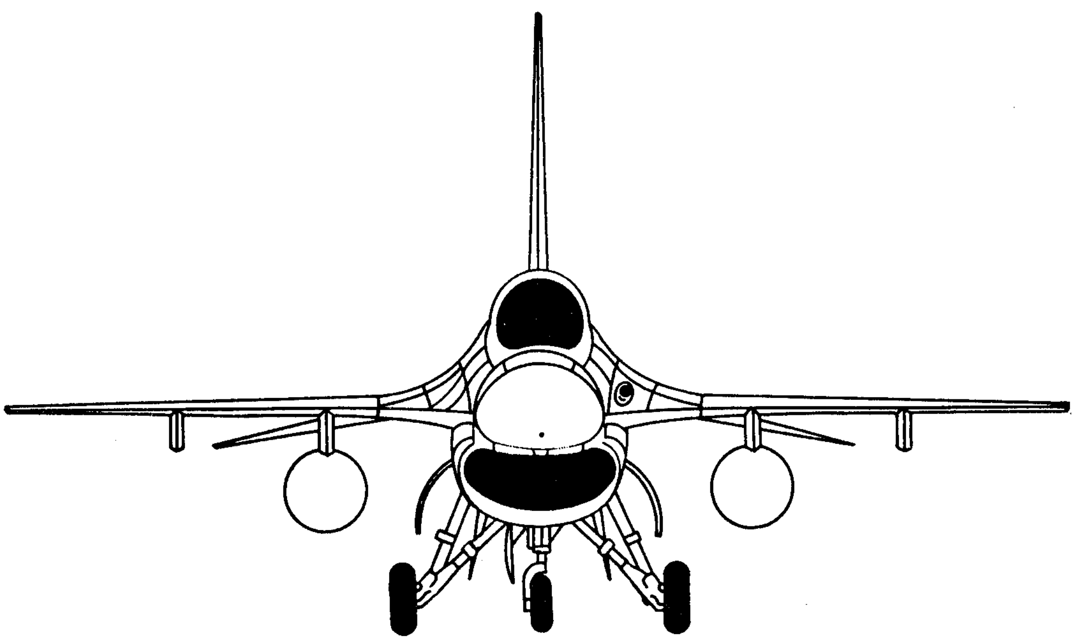
Benefits for Hardware Builders and Users

The benefits to designers and manufacturers of aerospace and ordnance equipment are:

1. Greater understanding of the new materials' behavior in service.

2. Improved ability to evaluate P/M alloys for cost effectiveness relative to improved properties and performance.

3. Knowledge required for efficient use of wrought P/M alloys in design and manufacture of finished products. Experience to date indicates when using wrought P/M alloys there is no need to change the fabrication processes from those used with ingot metallurgy alloys.



Benefits to the Material Producer

Through joint participation in the evaluation of these new wrought P/M alloys, Alcoa expects to increase its understanding of the production processes and how they affect properties and costs of finished parts.

Such understanding will be part of the evaluation of the feasibility of expanding production facilities and will provide assurances that the new plant will be most efficient and productive -- able to produce wrought P/M alloys at the lowest possible cost and highest possible quality. For example, evaluation of direct extrusion of products from green compacts, eliminating the canister, is underway.

In addition, an improved understanding of present wrought P/M alloys' performance will enable Alcoa to more accurately predict in-service behavior of future P/M alloys during their development.

Future Wrought P/M Alloy Developments

Development of other wrought P/M alloys is well along. Experimental alloys have been produced with special properties. Alloys with yield strengths up to 124 ksi, with high modulus-density ratios or with increased high temperature strength are in initial stages of evaluation.

Billets of a 3,000 pound size have been produced and Alcoa has an active program for development of even larger billets for rolling sheet and plate.

Availability

Alcoa can produce alloy X7090 and alloy X7091 extruded bar, rod and shapes from the present 110 pound billets and from 350 pound billets scheduled to be available in the near future. Die forgings and hand forgings can also be produced from the same size billets. Some shapes can be made from available dies; such as extruded bar 1.5 inches (38.1mm) x 4.5 inches (114.3mm) cross-section, an extruded seat track section, a ribbed die forging (Figure 6), or hand forgings.

Rolled plate and sheet are not currently available.

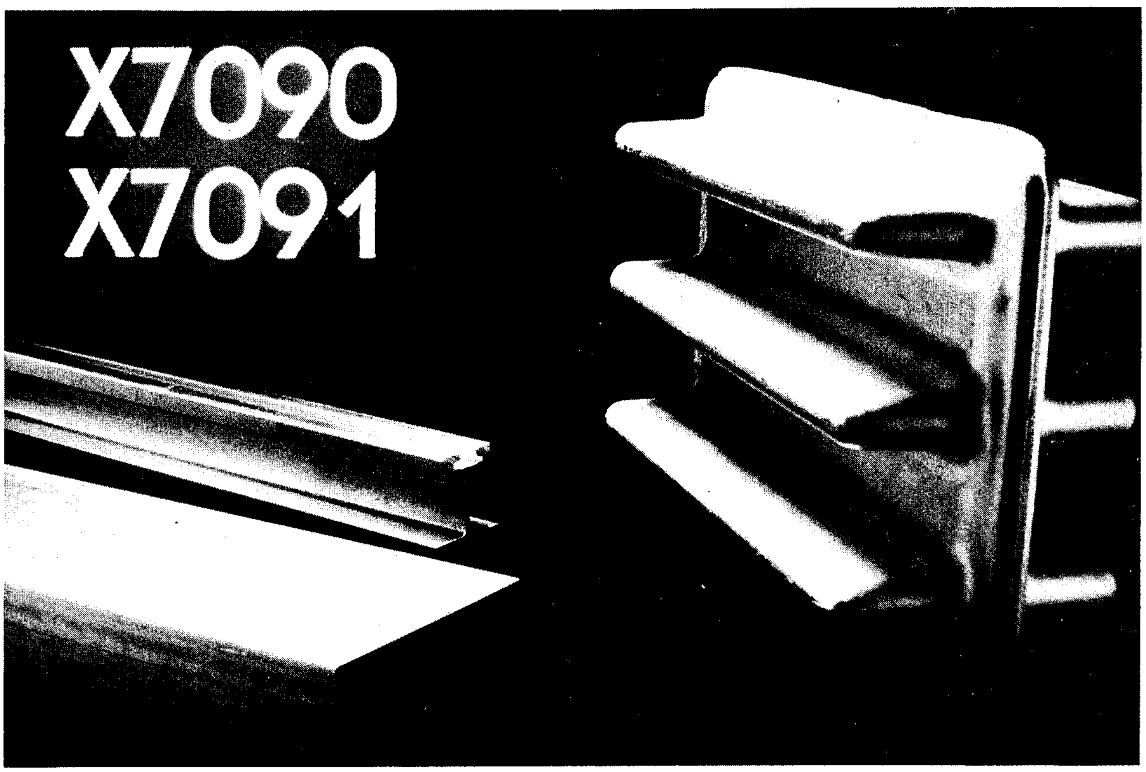


Figure 6

POTENTIAL FOR NEAR NET SHAPES

J. Stanley Mosier and Peter G. Bailey
General Electric Company

POTENTIAL FOR NEAR NET SHAPES

J.S. MOSIER and PETER G. BAILEY

AIRCRAFT ENGINE GROUP
GENERAL ELECTRIC COMPANY
CINCINNATI, OHIO

In recent years the demand for improved cost-effectiveness in shape making and fabrication processes and better utilization of input materials has brought about developments and advancements in near-net-shape technology. As a result, more refined shapes, reduction of costly input material and substantial product machining savings are achievable. In most cases that we have studied, reduction of input raw material is ~50%. Near-net-shape technology becomes increasingly important for the aerospace industry with rising fuel costs and increased concern over energy and material supply.

About 80% of the materials used in today's aircraft gas turbines are critical metals such as titanium and nickel-base superalloys. In order to improve the fuel efficiency of these engine systems, the aerospace industry has continuously developed new compositions for these alloy systems that are stronger, lighter, and with higher temperature capabilities. However, the new alloys are often more expensive, more difficult to fabricate and produce products with very high buy-to-fly weight ratios. Typically, a conventional forging can weigh 10 times as much as the finished part made from it. Near-net-shape technology thus becomes a viable alternative to conventional methods for the manufacture of costly, difficult to fabricate materials.

The materials resource crunch has had wide public exposure recently. One example is the February, 1981 Reader's Digest article "Strategic Materials: The Invisible War". Of the 36 non-fuel minerals essential to the United States as an industrial society, we are crucially dependent on foreign sources for 22 of them. In 1980, we imported 91% of our chromium, 93% of our cobalt, and 97% of our tantalum and manganese. By contrast, we were only 42% dependent on imported oil. Conservation of materials through near-net-shapes technology will become increasingly important as a national priority.

The need for total productivity improvement, including material conservation, is as popular today as the theme from "Star Wars", and has been identified as a major corporate thrust for most U.S. manufacturers. Projected escalation estimates indicate that by 1984 labor will be up 250% from 1973 levels and the cost of some of the high usage materials such as copper, aluminum and steel will increase 200-300% during the same period. The results of such escalation will be even more acute in the area of specialty aerospace materials. For example, prices of certain nickel-base superalloys increased 60% in the period from 1978 to 1979. Near-net-shape processes offer the opportunity for significantly improving productivity by reducing labor, material, and inventory costs as well as curbing material usage.

General Electric's Aircraft Engine Group has, throughout its' 30-year history, employed near-net-shape technology. Precision casting is probably the oldest of these technologies. In the 1960's, J79 turbine shafts were produced by shear spinning. Precision ring rolling and pioneering efforts of inertia welding engine rotor spools began in the early 1970's. All of these developments reduced the input weight of materials. Inertia welded spool construction also reduced the weight of the finished engine parts by eliminating flanges and bolts.

Except for precision casting, the previously mentioned applications are not normally thought of today as near-net-shape processes. Currently, we are looking at all possibilities to reduce input material.

Precision casting - inherently a near-net, or in some cases a net shape process, is dated by Chinese artifacts to at least 3000 B.C. Today it still has exciting potential. Capability for larger and more complex titanium and superalloy shapes are being developed, not only to replace heavier conventional forgings, but in some cases to eliminate the need for fabrication. Savings from some applications are in excess of $7,000 per part. The cost of the part made by casting is not always reduced drastically, but the savings in machining and fabrication can be very large. Investment in new machine tools to increase capacity can be reduced. Combined with hot isostatic pressing, the cast properties can also be enhanced. In some smaller and less demanding engine applications these precision investment castings can be used to make integrally bladed disks.

As previously mentioned, ring rolling and shear spinning are also finding new uses today by General Electric to produce near-net-shapes. In many cases material input reductions of 50% and more can be made with cost savings ranging from a few hundred to several thousand dollars per part.

In the 1960's, the Aircraft Engine Group began working with nickel-based superalloy powder metals. This is an extremely complex technology with many possible process variations. Manufacture of powder can employ rotating electrode, rotating disk, and commercial rapid solidification gas atomization techniques, to name just three. Containers into which the powder is placed for consolidation can be made of glass, ceramic, sheet or thick metal dies. Densification has been performed by direct hot isostatic pressing, extrusion, furnace consolidation at atmospheric pressure and direct forging. The first three consolidation techniques mentioned have also been combined with subsequent forging or rolling operations.

In addition to the nickel-based superalloys, we at GE have also worked with titanium powders. Currently, we are working under Air Force contract to establish today's cleanest production powder technique.

As demonstrated by our NASA "Materials for Advanced Turbine Engine" contract work, completed in 1979, typical Rene' 95 input material reductions for powder metal processes are 50%. Cost reductions indicated by this work were 35-40%, versus conventional forgings of the same alloy. Original projections of total payoff were $8-10 million per year. However, as with the current titanium powders, cleanliness became a major concern. Increased quality control measurements imposed, significantly altered these projections. To realize the total material and cost benefits that can be derived from direct hot isostatic compaction of powder metals, additional development is required. The powder metal potential is enormous, but realizing the entire near-net-shape objective remains a future target for the aerospace industry.

Hot die and isothermal forging are also part of the industry arsenal of near-net-shape techniques. Today these processes can hold closer tolerances than hot isostatically compacted parts and are cost competitive. Either of these forging processes can be employed on conventional ingot product as well as with powder consolidation, as mentioned previously. However, all desired configurations cannot be forged to the nearest-net-shapes.

Cost benefits comparison of the various near-net-shape processes is a terribly complex issue. General Electric is now involved in an Air Force sponsored effort to establish near-net-shape process mathematical models. Each of the technologies mentioned has its specific advantages and limitations over the others, depending on part size and geometry, as well as the type of material, but information in this arena is rather limited. In order to determine the feasibility of a given near-net-shape process and the economics of alternatives, this program addresses the need for a data base of part geometry, function, materials, tolerances and costs. Several aerospace companies are participating in this Air Force work.

Like steak versus spare ribs, near-net-shapes cost more per pound than conventional products - but the advantages in overall economics are enormous. The actual per shape cost is less and processing cost as well as facility requirements are dramatically reduced. Implementation of near-net-shapes technology should be a major tool for addressing the intent of our National Materials Policy.

J.S. Mosier

OUTLOOK FOR AS-HIP'ED NEAR NET SHAPES

John Moll
Colt/Crucible Research Center

OUTLOOK FOR AS-HIPED NEAR-NET SHAPES

by

J. H. Moll*

Presented
at

Workshop on Conservation and Substitution
Technology for Critical Materials

Nashville, Tennessee
June 15-17, 1981

*Technical Director, P/M and Welding, Crucible Research Center

OUTLOOK FOR AS-HIPED NEAR-NET SHAPES

ABSTRACT

Within the last decade, a powder metallurgy (P/M) process has emerged which offers marked savings of critical materials and energy. The process involves the use of pre-alloyed powders, near-net shape technology, and hot-isostatic-pressing (HIP). The application of this technology to tool steels, superalloys and titanium alloys are discussed. The application of this technology to tool steels has resulted in materials which use less critical materials and perform more efficiently. P/M superalloy turbine engine hardware is currently in production as near-net shapes. The result has been a reduction in critical input materials as well as energy savings. The development of P/M titanium near-net shapes is currently in progress. The technology promises a marked reduction in the amount of titanium required to produce airframe and engine hardware.

OUTLOOK FOR AS-HIPED NEAR-NET SHAPES

Introduction

Conventional processing of metals often results in considerable waste of material and energy. As a result, there is a need throughout industry for the direct production of net or near-net parts. This is particularly important in the production of high speed tool steels, superalloys and titanium alloys which contain high concentrations of critical elements such as cobalt, chromium, tantalum and titanium. More efficient use of these materials is necessary.

While powder metallurgy (P/M) technology has existed for many years, it is only in recent times that P/M has been applied to produce shapes of tool steels, superalloys and titanium in an effort to conserve materials which are in short supply. A unique P/M process has been developed to produce near-net parts. This process involves hot-isostatic-pressing (HIP) of powder-filled shaped containers. In addition to material savings, this as-HIPed product offers other benefits such as greater uniformity of product, property advantages of finer structures, and fewer finishing operations.

P/M Shape Process

Figure 1 shows the Crucible P/M process for making shapes from metal powders. Tool steels and superalloys are gas-atomized. In this process, high pressure gas is used to atomize a molten stream of air or vacuum induction melted metal. The resulting powder falls into a liquid gas quench at the base of the chamber. The spherical nature of this powder, Figure 2, is ideal for producing shaped P/M parts. Subsequent processing of the powder involves screening and blending to obtain a uniform size distribution.

The processed powder is subsequently loaded into shaped containers. Two basic types of containers are currently used, steel and ceramic. Production containers are made from metal and may be produced from welded pipe to produce simple cylindrical shapes. More complicated shapes may be produced from low-carbon or stainless steel sheet. A process for making very complex shapes using a ceramic mold is currently being developed. Ceramic molds are made by a process similar to the lost wax process. An oversize wax and/or plastic pattern, Figure 3, can be made by machining or injection casting. After a series of ceramic dip coatings, dryings, dewaxing and firing, the ceramic mold is ready for powder filling, Figure 4.

Once metal containers are fabricated and cleaned, they are loaded with powder, evacuated and sealed. Ceramic containers are loaded with powder, placed in an outer steel can and surrounded by a secondary pressing media, Figure 5, and then evacuated and sealed.

The final step in the P/M shape process utilizes hot-isostatic-pressing (HIP). Sealed containers are placed in an autoclave, heated to temperatures ranging from 1600°F to 2200°F, depending upon the alloy, and pressed under 15,000 psi gas pressure. The result is a fully dense product. Figure 6 shows the wide variety of shapes which can be produced by the P/M process.

The process for producing P/M titanium alloy shapes is similar to that described for tool steels and superalloys except that powder is produced by the rotating electrode process of Nuclear Metals, Inc., Figure 7. A tungsten-arc or plasma-arc provides localized melting at the end of a titanium alloy bar while the bar is rapidly rotated. The rotating motion of the bar spins off molten particles which subsequently solidify in the enclosing evacuated chamber. The resulting powder is spherical, Figure 8, and similar to gas-atomized powder.

P/M Tool Steel Shapes

Tool steel products made from gas-atomized powder have been in production for more than ten years. These materials offer a number of advantages over their conventionally-produced counterparts. These include the following[1]:

(1) Superior grindability.
(2) Improved toughness.
(3) Cross-sectional uniformity of hardness.
(4) More uniform size change.

Tool steels are highly alloyed materials, often containing substantial quantities of critical elements such as chromium and cobalt. Table I gives compositions of several highly alloyed tool steels which are currently produced by the powder process.

In addition to improved performance, the P/M process offers the ability to conserve critical materials by producing as-HIPed shapes. Figure 9 shows a pressed-to-shape hollow bar. This bar was produced using concentric low-carbon steel pipes formed into a powder container. Hollow bars can be produced to nine feet in length and three-and-one-half feet in outside diameter. Typical applications include cutting tools, punches, shafts, broaches, and tube drawing preforms. Using conventional ingot technology, hollow shapes would be made by metal working and/or machining.

Tool material savings can also be achieved through the use of composite and near-net shapes made by the P/M process. Figure 10 shows a shaper cutter blank made by bonding M2 tool steel to the outside diameter of a carbon steel core. With this technique, the highly alloyed material is used only where required (i.e., at the outside cutting surface). Figure 11 shows a near-net shape hob produced from tool steel powder using the ceramic mold process.

P/M Superalloy Shapes

Superalloys are widely used in turbine engines. These alloys, normally nickel or cobalt based, contain substantial quantities of critical materials such as chromium, cobalt, titanium, and in some instances, tantalum. Table II gives the critical element content of a number of widely used alloys. Hardware produced from these alloys typically exhibits a high "buy-to-fly" ratio, often as high as 20:1. A marked reduction in input material can be achieved by P/M shape technology. Figure 12 compares the processing sequences used for a P/M shaped engine shaft and a conventional cast and wrought engine shaft. The savings in starting material, number of processing steps, and machining can be noted. Figure 13 shows the as-HIPed engine shaft and the detail that can be made with P/M.

P/M superalloy hardware is currently being produced from powder to near-net sonic shapes using metal containers by Crucible Compaction Metals. These range from relatively small turbine disks, Figure 14, to large turbine components, Figure 15. An Air Force-sponsored P/M program[(2)] is currently in progress to reduce the input weight on a large, 32-inch diameter, turbine disk for Pratt & Whitney Aircraft's JT9D engine, Figure 16. The current input weight for this part is 800 lb. To date, work under the program has reduced the input weight to 550 lb. Further weight reductions of 40-50 lb are planned.

The P/M process can also be utilized to produce multi-component parts. Using current technology, engine spools are normally assembled from parts made from several individual forgings. With the P/M shape process, the spools can be made as a single piece. The result is a marked reduction in input weight and the elimination of a number of processing steps.

A sectioned container for a complicated spool is shown in Figure 17. In this instance, the spool is comprised of six segments: a shaft at the top, 4 compressor disks, and a bolt flange on the bottom. The total input weight of individual components is 490 lb. Made as a single component, the total weight is 210 lb; a material savings using P/M multi-component technology of 280 lb per engine.

Parts produced by the P/M HIP process are fully dense and mechanical properties compare well with forgings and meet specification or target requirements. For Rene 95, cut-up test specimens for many disks show the strength and ductility levels and the statistical deviations in room- and elevated-temperature properties to be excellent, Table III. The 1200°F rupture and creep properties also meet specification requirements. MERL 76 as-HIP tensile properties, Table IV, meet strength and ductility goals set in an Air Force program[2].

P/M Titanium Alloy Shapes

P/M titanium is newer and not as far advanced as tool steels and superalloys. An intensive effort is currently in progress to develop the ceramic mold process for producing near-net engine and airframe hardware from titanium alloy powder. Initial studies[3] were conducted using relatively small parts such as the keel splice former shown in Figure 18. The conventionally forged part weighs 4.67 lb whereas the HIP near-net shape weighs about 1.0 lb. In addition to materials savings, analysis, Table V, shows an energy savings using the P/M process for near-net titanium alloy parts.

Excellent progress is being made in a current Air Force/ Crucible manufacturing technology project[4] aimed at producing large titanium airframe parts and complex engine parts. The target near-net parts being made in this program are listed in Table VI. Considerable material, machining and production time can result from the P/M near-net shape process.

The following are several different types of as-HIPed Ti-6Al-4V airframe parts:

(1) A drop-out link for the McDonnell-Douglas F-15 fighter, Figure 19, is a large, deep-pocketed part typical of many titanium airframe parts. The weight of the as-HIPed part is 54 lbs compared to a forging weight of 94 lbs.

(2) The Northrop arrestor hook support fitting for the F-18 fighter, Figure 20, is the largest P/M part made to date. The weight of this as-HIPed first trial part was 60 lb compared to a forging weight of 175 lbs.

(3) The Boeing walking beam support fitting for the 747 landing gear, Figure 21, represents another type of airframe titanium shape. The as-HIP weight is 30 lbs. The forging weight is 50 lbs.

The program also involves several P/M Ti-6Al-4V engine parts which include the following:

(1) Figure 22 shows a compressor spool for General Electric's TF34 engine. The as-HIPed weight, including an added test ring, was 70 lbs. The forging for this part weighs 104 lbs.

(2) The Williams Research compressor rotor for the F-107, Figure 23, shows that thin complex blades, attached to the base, can be made by the ceramic mold process. The part is currently machined from a pancake forging weighing 30 lbs. The as-HIPed weight is 5.5 lbs.

The properties of P/M as-HIPed Ti-6Al-4V meet many current specifications. Table VII compares the properties of as-HIPed standard composition powder with requirements of AMS 4928H[4]. Tensile properties meet specification requirements in different test directions. Good fracture toughness is also indicated. Properties of as-HIPed Ti-6Al-4V made from extra low interstitial (ELI) powder, Table VIII, compare favorably with typical wrought mill annealed material and readily meet MMS-1225 specification properties[5]. Excellent fracture toughness values, K_Q, have also been observed.

As-HIPed near-net parts have also been produced from Ti-6Al-6V-2Sn alloy powder. This process was developed at Crucible Research Center and is currently being applied and tested for various specific applications under Navy sponsorship at Grumman. One of these involved a fuselage brace for the F-14A aircraft[6]. Figure 24 shows a pilot production lot of these braces ready for shipment to Grumman. Work is currently in progress, under Navy sponsorship, to produce a large, 48-inch, nacelle frame using as-HIPed P/M Ti-6Al-6V-2Sn shapes[7]. The frame, Figure 25, will be HIPed as four individual components which will subsequently be joined by electron beam welding to produce the final nacelle frame.

Summary

Conventional manufacturing procedures often use excessive material and energy to produce final parts. A P/M near-net shape process has been developed to reduce input material and conserve critical materials. The process involves hot-isostatic-pressing (HIP) of powder-filled shaped containers. Shaped parts are currently in production for tool steels and superalloys using steel containers. Complex tool steel, superalloy and titanium shapes are being developed using a ceramic mold process. The properties of fully dense as-HIPed shapes generally meet or exceed those of conventional cast plus wrought material.

"The material contained in this paper is intended for general information only and should not be used in relation to any specific application without independent study and determination of its applicability and suitability for the intended application. Anyone making use of this material or relying thereon assumes all risk and liability arising therefrom."

REFERENCES

(1) A. Kasak and E. J. Dulis, "Powder Metallurgy Tool Steels" Powder Metallurgy, No. 2, 1978.

(2) "Manufacturing Process for Production of Near-Net Shapes by Hot-Isostatic-Pressing of Superalloy Powder" Air Force/Pratt & Whitney Aircraft Contract No. F33615-77-C-5187.

(3) J. H. Schwertz, V. K. Chandhok, V. C. Petersen, and V. R. Thompson, "Consolidation of Titanium Powder to Near-Net Shapes" Final Report AFML-TR-78-41, May 1978.

(4) V. C. Petersen and V. K. Chandhok, "Manufacturing Process for the Hot-Isostatic-Pressing of Large P/M Shapes" Interim Report AFML-IR-184-7T(I), June 1979.

(5) G. Chanani, W. Highberger, C. Kelto and V. C. Petersen, "Application of Titanium Powder Metallurgy for Manufacture of a Large and Complex Aircraft Component" Powder Metallurgy of Titanium Alloys, AIME, 1980

(6) R. Witt and J. Magnuson, "Flight Qualification of Titanium F-14A Airframe Components Manufactured by Hot-Isostatic-Pressing" Final Report, Contract No. N0019-76-C-0143, Naval Air Systems Command, June 1977.

(7) "Electron Beam Welded HIP Structures" Navy/Grumman Contract No. N00019-80-C-0034.

Table I

COMPOSITION OF SEVERAL TOOL STEELS
MADE BY THE P/M PROCESS
(Weight %)

Alloy	C	W	Mo	Cr	V	Co
M2	1.0	6.0	5.0	4.0	2.0	-
M4	1.3	5.5	4.5	4.0	4.0	-
M42	1.1	1.5	9.5	3.7	1.5	8.0
T15	1.5	12.0	-	4.0	5.0	5.0

Table II

CRITICAL ELEMENT CONTENT
OF SEVERAL SUPERALLOYS
USED IN ENGINE DISKS
(Weight %)

	Astroloy	IN-100	Rene 95	MERL 76	IN-718	Waspaloy	PA-101
Chromium	15	10	14	12	19	19	13
Cobalt	17	15	8	19	-	14	9
Titanium	3	5	2.5	4	1.0	3	4
Tantalum	-	-	-	-	-	-	4

Table III

CUT-UP PROPERTIES OF AS-HIP RENE 95 TURBINE DISKS[a]

Properties	Spec	Mean	σ
R.T. Tensile			
Ultimate (ksi)	225.0	239.4	2.8
Yield (ksi)	163.0	176.9	3.5
Elongation (%)	10	17.2	1.9
Red. of Area (%)	12	20.5	1.8
1200 F Tensile			
Ultimate (ksi)	205.0	220.1	5.4
Yield (ksi)	153.0	165.2	4.9
Elongation (%)	8	13.8	4.1
Red. of Area (%)	10	16.5	3.3
Stress Rupture[b]			
Life (hr)	50	88.8	26.3
Elongation (%)	3.0	6.5	2.1
Creep[c]			
Time (hr)	50	54.6	6.7
Elongation (%)	0.3 max	.10	.08

[a]First 75 engine sets (150 disks).

[b]1200 F/150 ksi.

[c]1100 F/150 ksi.

Table IV

TENSILE PROPERTIES OF HIP MERL 76 POWDER[a]

Test Temperature (^{o}F)	Yield Strength (ksi)	Ultimate Strength (ksi)	Elongation (%)	Reduction of Area (%)
Test Data				
RT	158	226	17	19
1000	152	203	12	19
1150	154	213	12	15
1300	152	187	22	22
Target Properties				
RT	154	223	15	15
1300	150	174	12	12

[a]Heat Treatment: 2125 F/1 hr/1500 F salt quench + 1400 F/16 hr/air cool

Table V

COMPARISON OF ENERGY REQUIREMENTS
FOR CONVENTIONAL FORGINGS AND
P/M AS-HIPED TI KEEL SPLICE FORMER

Process	Energy Requirements (kwh)	
	Conventional Forging	P/M Shape
Bar Product	301.7	72.7
Forging	1.8	-
Atomization	-	.7
HIP	-	52.0
Machining	.5	.1
Total	304.0	125.5

Table VI

WEIGHT COMPARISONS OF PARTS SELECTED
FOR P/M TITANIUM

Sub-Contractor	Part	Alloy	Part Weight (lb)			
			Forging		HIP	Final Part
			Billet	As-Forged		
Boeing	Walking Beam Support (747)	Ti-6-4(STD)	55	50	30	21
GD/Fort Worth	Horizontal Stabilizer Pivot Shaft (F-16)	Ti-6-4(ELI)	148	120	65	32
GE/AEG	Compressor Spool 3-8 (TF-34 Engine)	Ti-6-4(STD)	147	104	70	15
MCAIR	Drop-out Link (F-15) Keel Splice Former (F-15), Near-Net	Ti-6-4(STD)	115 6	94 4.7	54 0.9	13.8 0.4
Northrop	Arrestor Hook Support Fitting (F-18)	Ti-6-4(ELI)	-	175	60	28.4
P&WA	3rd Stage Fan Disk (F-100 Engine)	Ti-6-2-4-6	120	94	70	27
Williams Research	Radial Compressor Rotor (F-107 Gas Turbine)	Ti-6-4(STD)	32	30	5.5	3.6

Table VII

ROOM TEMPERATURE TENSILE AND TOUGHNESS PROPERTIES FOR HIP Ti-6Al-4V (STANDARD) POWDER

Condition	Orien-tation	Yield Strength (ksi)	Ultimate Strength (ksi)	Elonga-tion (%)	Reduction of Area (%)	W/A[a] (in-lb/in.^{2})	Predicted K_Q[b] (ksi $\sqrt{in.}$)
As-HIP	LT	135	142	12	40	410	63
HIP + Vacuum	LT	132	139	13	38	565	73
Anneal	TL	130	138	12	35	578	74
(1300 F/8 hr/ slow cool)	ST	132	139	12	36	541	72
AMS Spec 4928 H		120	130	10	15	-	-

[a]Tested in compression mode.

[b]Predicted from $K_Q^2/E = 0.57$ (W/A)

Table VIII

ROOM TEMPERATURE TENSILE AND TOUGHNESS PROPERTIES OF HIP Ti-6Al-4V (ELI) POWDER

Condition[a]	Yield Strength (ksi)	Ultimate Strength (ksi)	Elonga-tion (%)	K_Q (ksi $\sqrt{in.}$)
As-HIP	124	135	15	84
Beta Anneal	130	138	10	87
Recrystallize Anneal	125	134	15	86
Mill Anneal	119	128	17	89
Typical Wrought (Mill Anneal)	115	125	12	-
MMS-1225 Spec (Annealed)	110	120	10	-

[a]As-HIP - No heat treatment

Beta Anneal - 1300 F/12 hr (vacuum degassed) 1750 F/30 min., 1865 F 15 min., air blast cool, 1300 F/2 hr/AC

Recrystallize Anneal - 1300 F/12 hr (vacuum degassed) 1759 F/2 hr/AC, 1400 F/2 hr/AC (to below 900 F in 45 min.)

Mill Anneal - 1300 F/12 hr (vacuum degassed) 1300 F/2 hr/FC (300 F/hr max) to 1000 F/AC

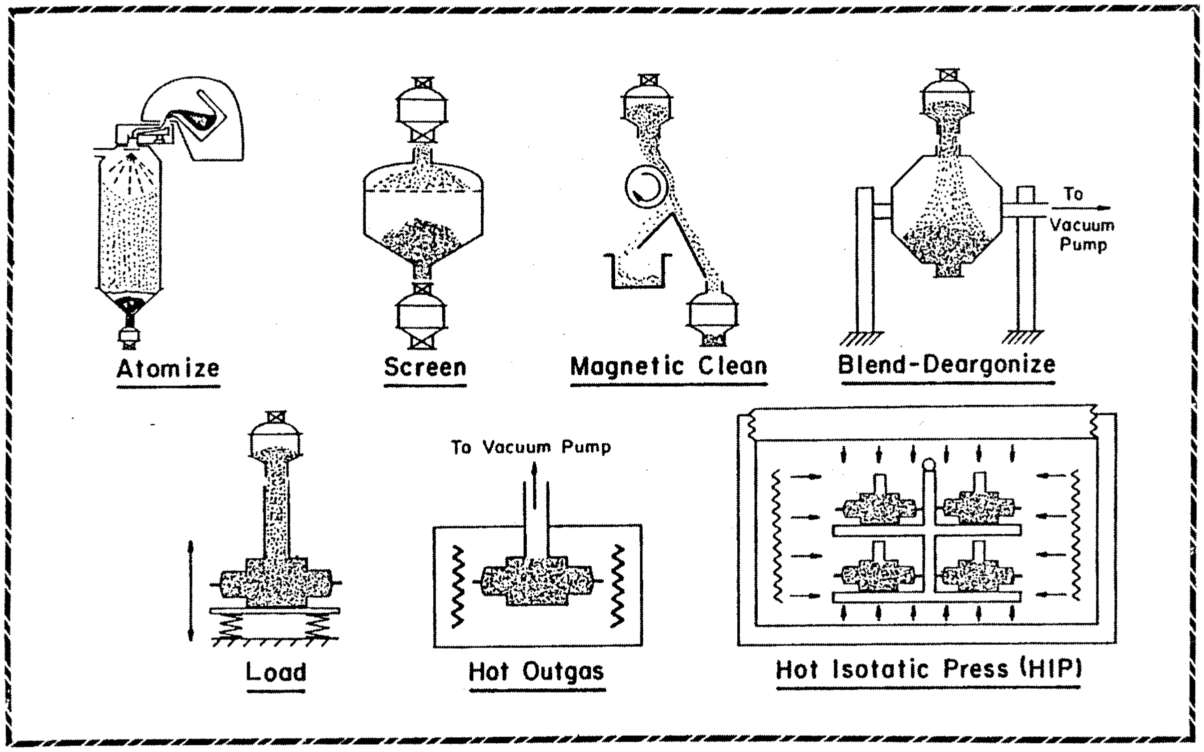
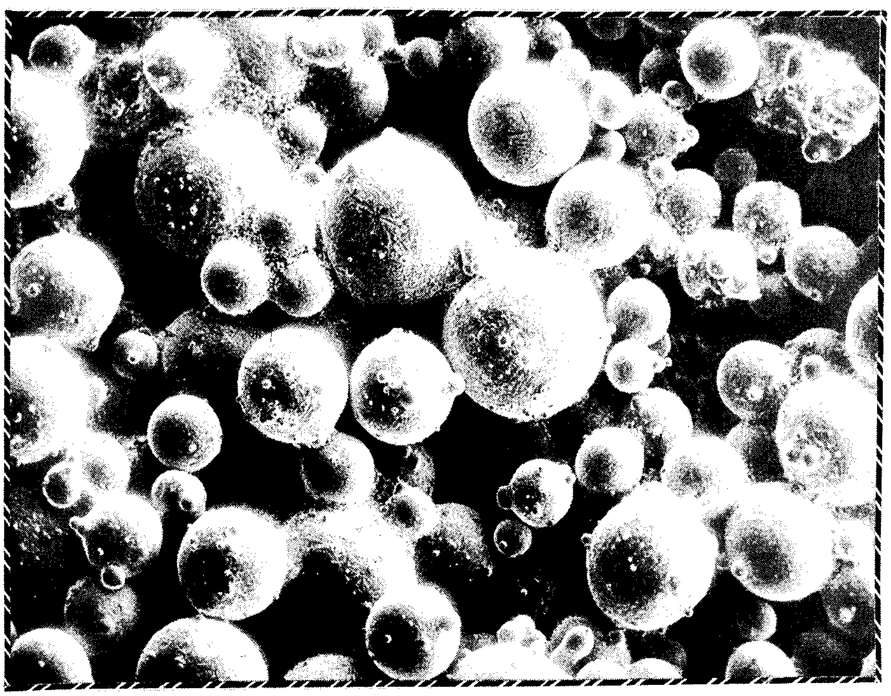
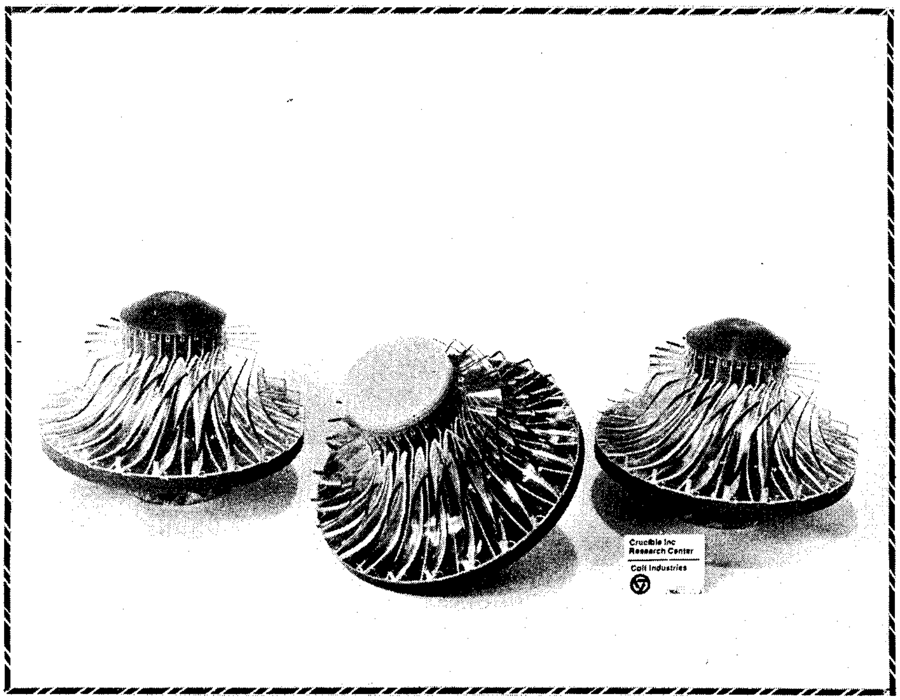


Figure 1. The Crucible P/M Superalloy Process.



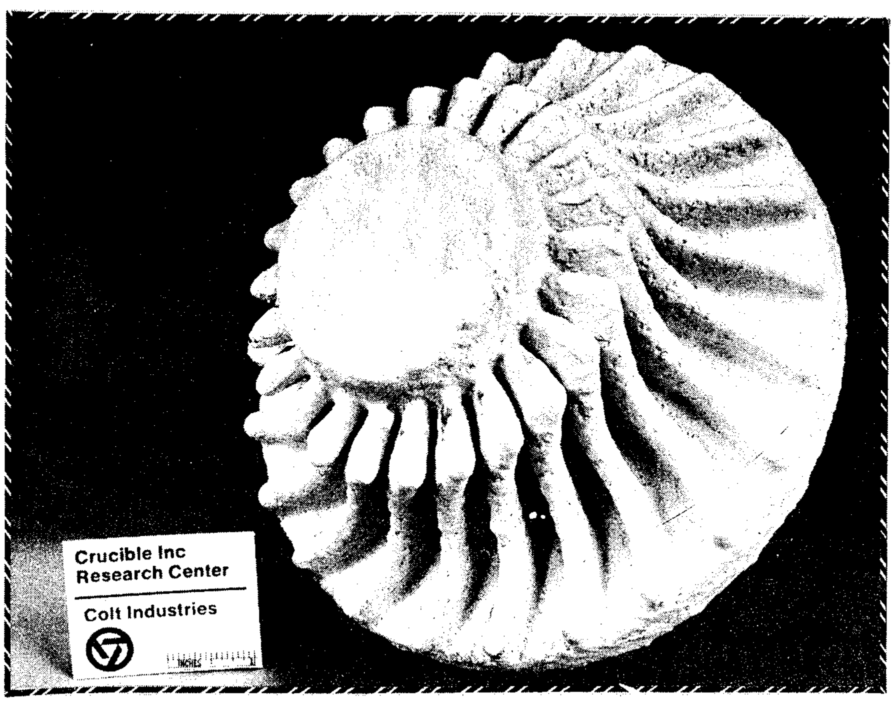
580-81

Figure 2. Argon Gas-Atomized Powder.



567-81

Figure 3. Plastic and Wax Patterns.



108-80

Figure 4. Ceramic Mold.

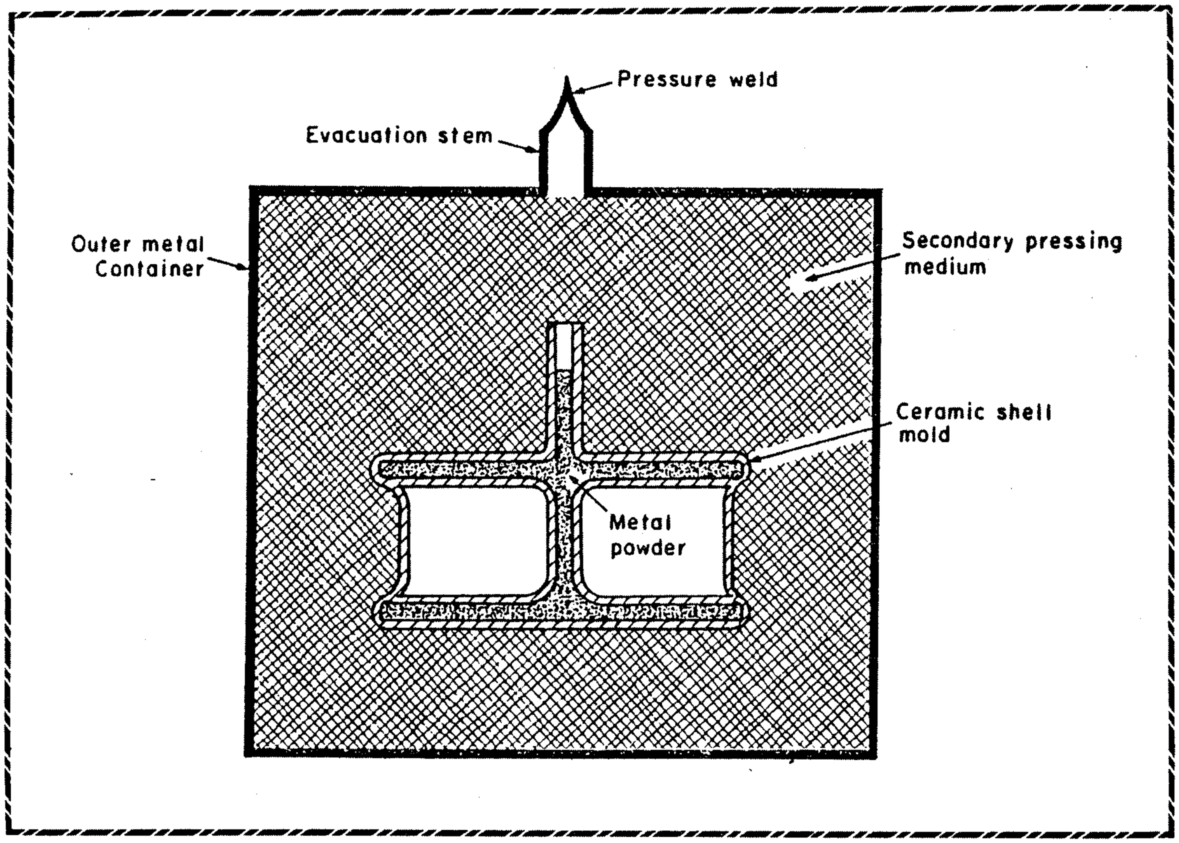


Figure 5. Container Assembly for Ceramic Mold Process.

554-78

Figure 6. Variety of Parts Made by P/M Shape Process.

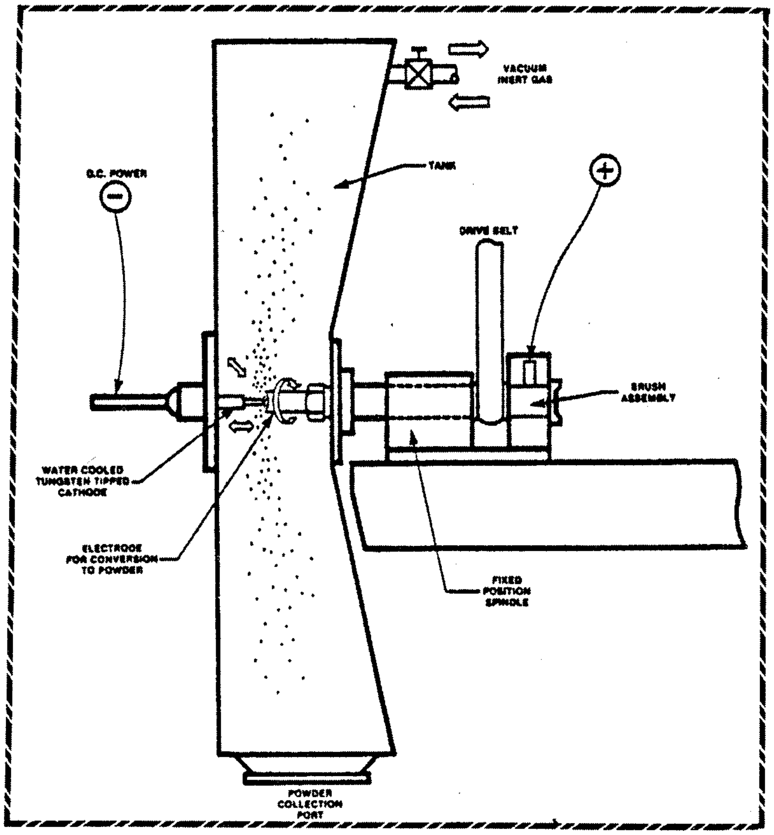
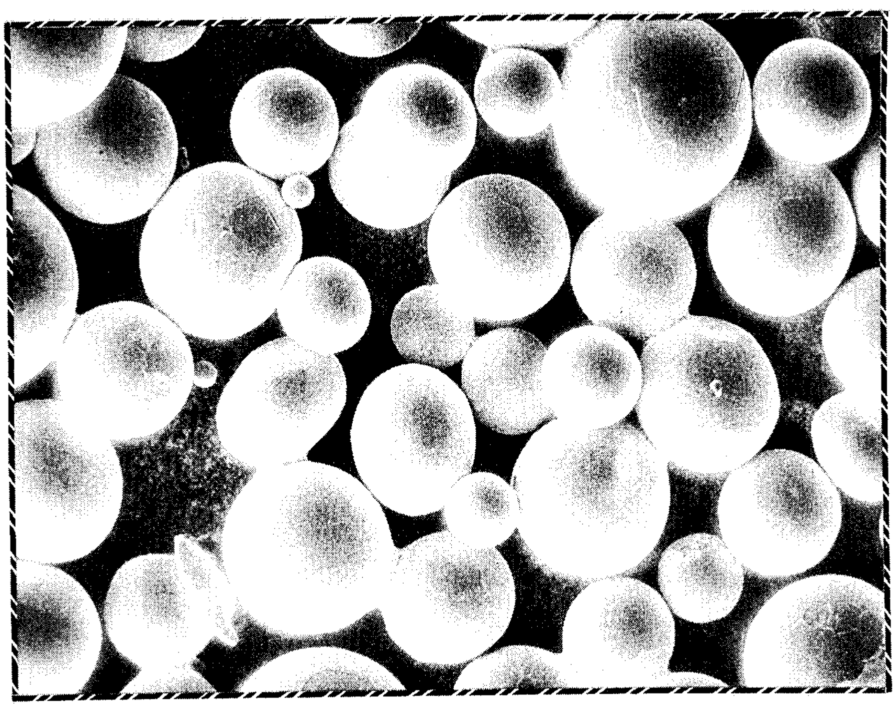
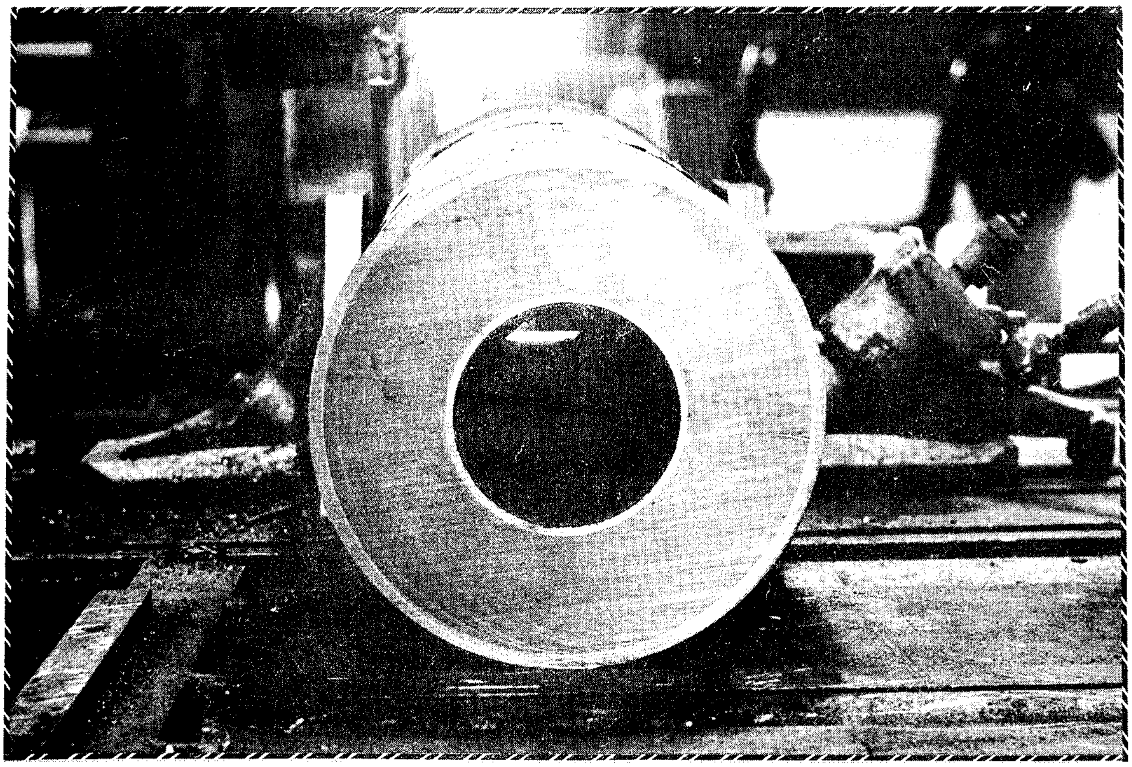


Figure 7. Rotating Electrode Process for Making Titanium Alloy Powder.



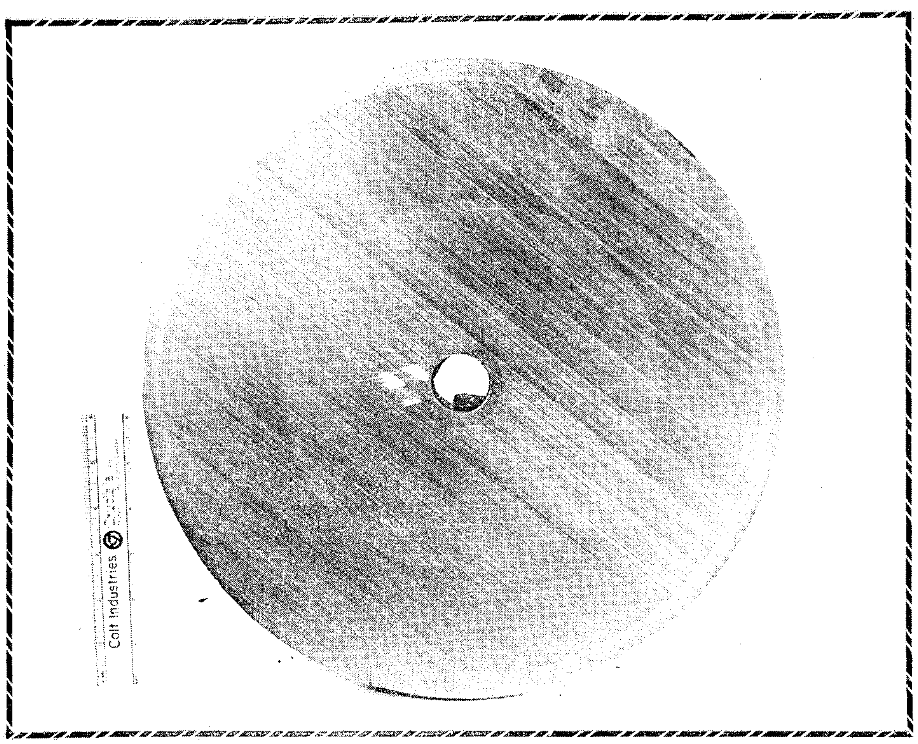
581-81

Figure 8. Rotating Electrode Titanium Alloy Powder.



671-73

Figure 9. Hollow Bar Produced by P/M Process.

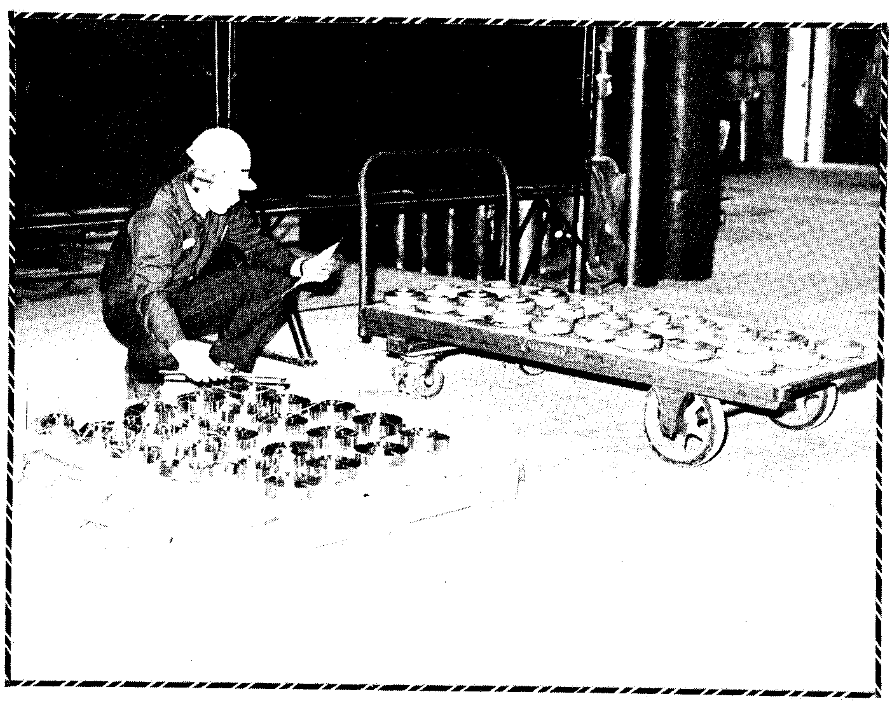


719-75

Figure 10. Composite Shaper Cutter Blank (Center - Mild Steel, Outside Diameter - M2 Tool Steel).

833-76

Figure 13. Large P/M Superalloy Engine Shaft Made Using Ceramic Mold Process.



253-78

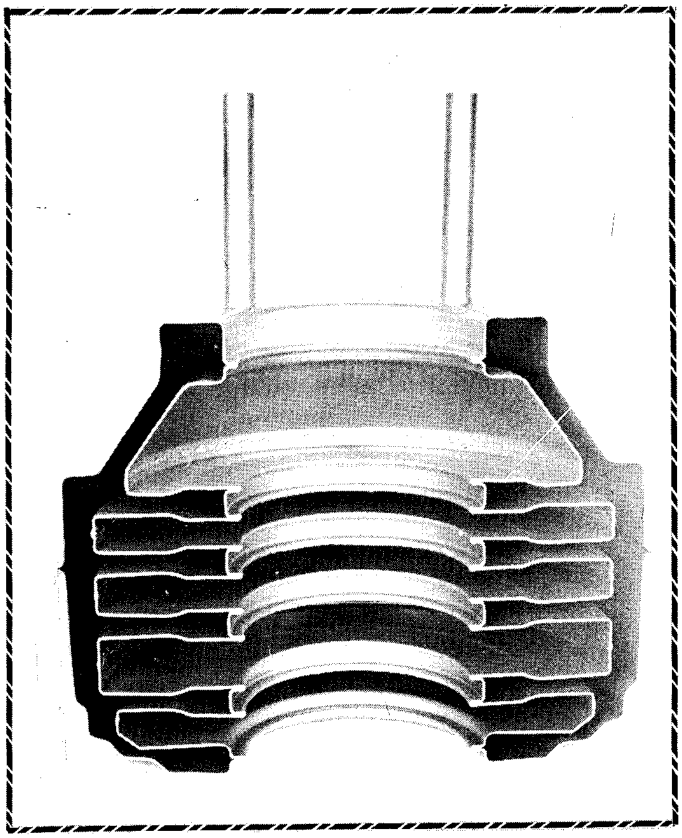
Figure 14. Small P/M Turbine Disks Made Using Metal Container.

251-78

Figure 15. Large P/M Turbine Disk Made Using Metal Container.

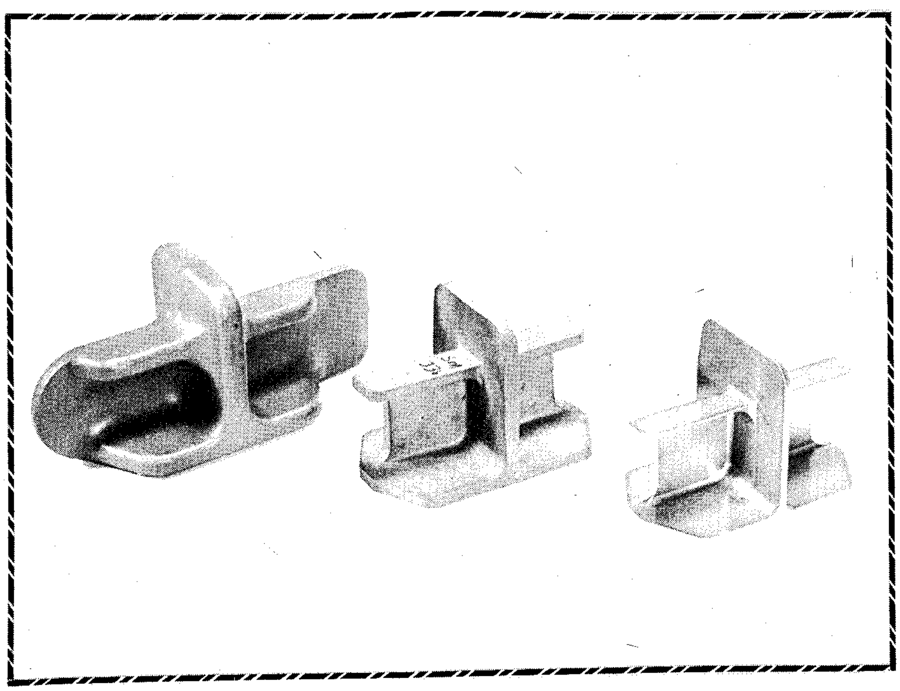
148-81

Figure 16. 32-Inch P/M Turbine Disk Made Using Metal Container.



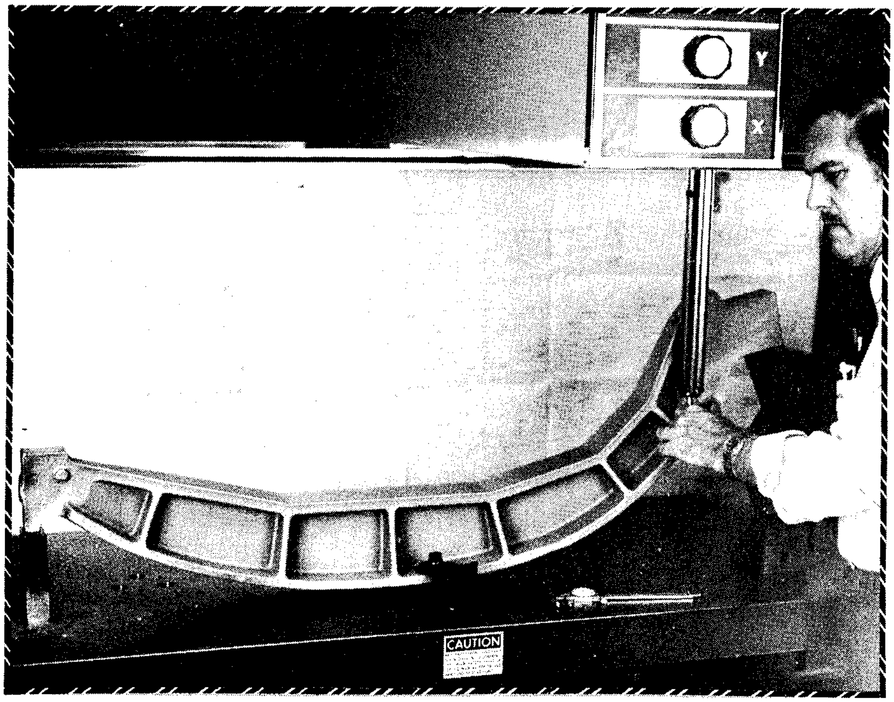
530-81

Figure 17. A Sectioned Container for a P/M Multicomponent Compressor Spool.



628-75

Figure 18. Keel Splice Formers - (Left - forging, Center - as-HIPed, Right - finished part).

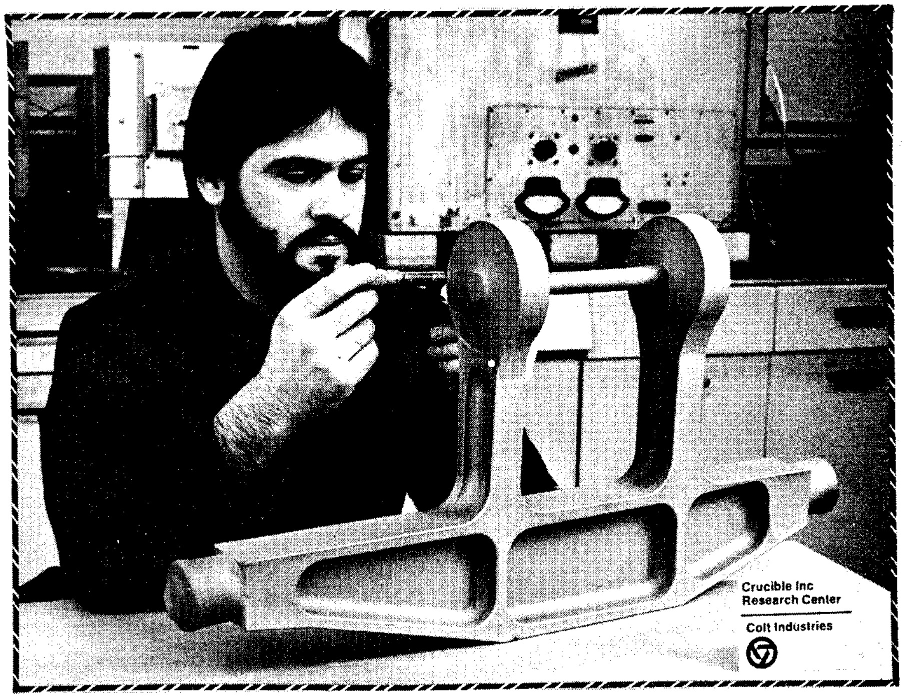


482-79

Figure 19. The McDonnell Douglas F-15 Drop-Out Link P/M Titanium Part.

748-79

Figure 20. The Northrop F-18 Arrestor Hook Support Fitting P/M Titanium Part.

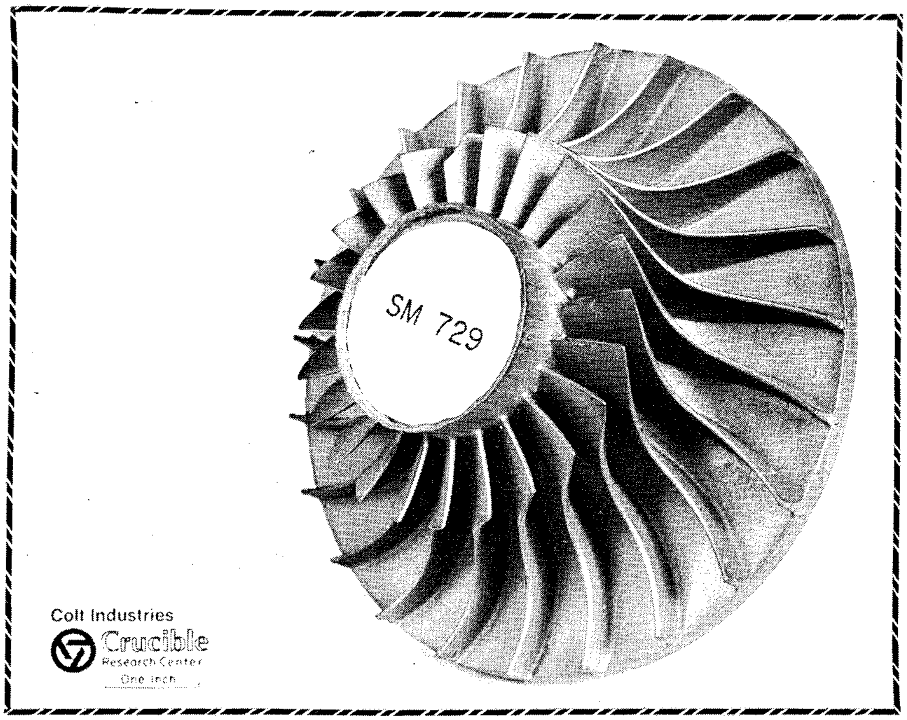


1038-79

Figure 21. The Boeing 747 Walking Beam Support Fitting P/M Titanium Part.

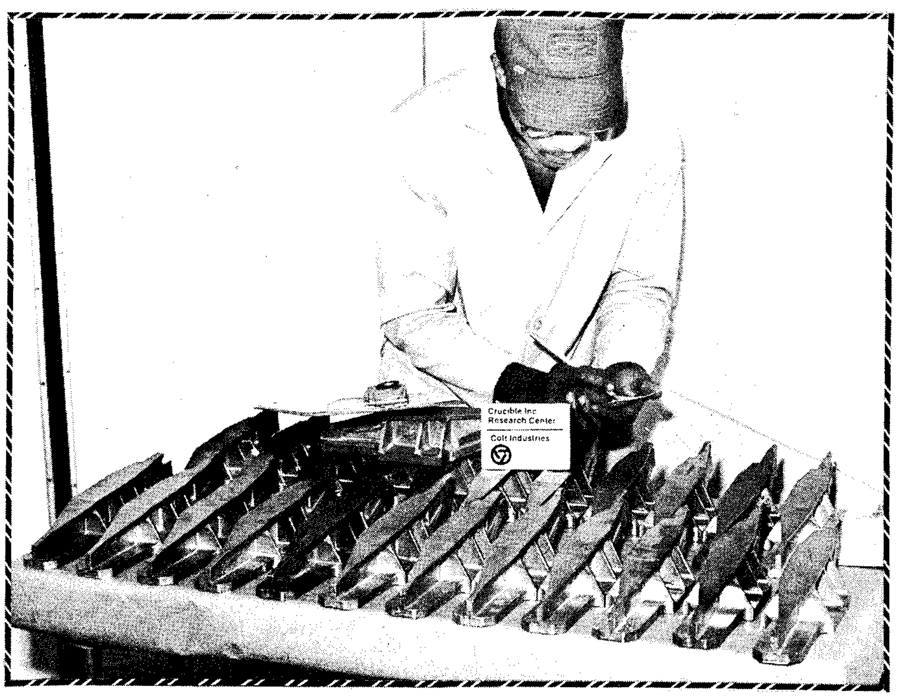
1019-79

Figure 22. The General Electric TF-34 Compressor Spool P/M Titanium Part.



181-79

Figure 23. The Williams Research F-107 Compressor Rotor P/M Titanium Part.



946-80

Figure 24. Grumman F-14A Fuselage Braces Made from Ti-6Al-6V-2SN Powder

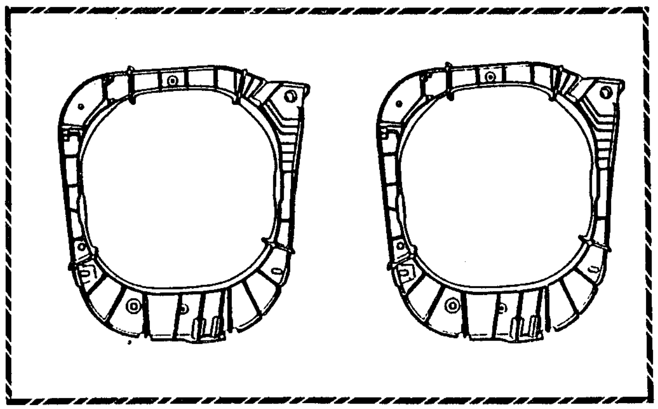


Figure 25. Large (48 inches x 40 inches) Nacelle Frames to be Made from Electron Beam Welded as-HIP Shapes using Ti-6Al-6V-2SN Powder.

TECHNOLOGICAL OPPORTUNITIES TO MORE FULLY UTILIZE METALS WITH DOMESTIC SOURCES OR NEAR DOMESTIC SOURCES AND SUBSTITUTES FOR CRITICAL METALS

Horace N. Lander
Climax Molybdenum Co.

"Technological Opportunities to More Fully Utilize Metals with Domestic Sources or Near Domestic Sources as Substitutes for Critical Metals"

Keynote Address for the Session

by

Horace N. Lander
Senior Vice-President, Research and Development
Climax Molybdenum Company
a Division of AMAX Inc.

INTRODUCTION

Welcome to the session with the longest title! As keynoter and chairman, I realize that by the time I explain the title, my time will be up and we can hear the speakers tell us how four metals readily available in the United States can substitute at least partially for four metals that could be unavailable at a future time because of some geopolitical crisis. You have attended several sessions in which critical materials have been defined, and sessions in which the speakers have reviewed techniques to reduce the use of critical materials. Our task in this session is to call your attention to four versatile alloying elements, and how best to utilize them to provide substitute materials that will perform as well as the materials highly dependent on more critical alloying elements.

SLIDE 1

Let us look again at the now very familiar bar chart defining U.S. reliance on imported metals. First of all, it is obvious that the critical metals are titanium, tantalum, chromium and cobalt. Manganese is also critical, but is not considered as serious as the other four because it is abundant in many areas of the world except North America, and it is considered unlikely that suppliers in all of the areas would limit their exports at the same time.

Next, it is evident that nickel, tungsten, vanadium and molybdenum are much less dependent upon imports. In fact, if we recognize Canada as the most reliable "foreign" source, then our import reliance from other sources is 30 percent or less for these four metals. For this reason, the present session will concentrate on the opportunities to use these four available elements (Ni, W, V, Mo) to substitute at least partially for these four critical elements (Ti, Ta, Cr, Co).

We shall ask the speakers, who are experts on nickel, tungsten, vanadium and molybdenum, to bring us up-to-date on the availability of these metals and the success to this point in efforts to use these metals as substitutes for titanium, tantalum, chromium and cobalt. I believe it can be a useful first step, however, to define alloy substitution, to take a realistic look at the various steps in the substitution process, and to discuss the stimulus for substitution.

STIMULUS FOR SUBSTITUTION

SLIDE 2

We shall deal with two major stimuli for alloy substitution -- to achieve an economic gain, or to accomplish a national strategic goal. Let us first deal with strategic substitution.

SLIDE 3

The factors involved in strategic alloy substitution, to reduce our dependence on alloys available from potentially unstable countries, are, first, the reliability of the various external supply sources. For many imported metals, the external sources are quite stable and reliable, and probably will remain that way. Reliability must be assessed in terms of geopolitical factors, usually by the federal government.

The other principal factor involved in strategic alloy substitution is the <u>effect</u> of disrupted metal supply. Disruption should be considered in terms of both the effect on the national defense capability, as well as the effect on the total economy.

SLIDE 4

In terms of the defense capability, even if technically adequate substitutes are not available, only a relatively small amount of total metal supply may be needed to satisfy defense needs. Because of these relatively small supply requirements for defense, a stockpile program is feasible, if it is <u>limited</u> to defense requirements. We could spend a great deal of time examining our past stockpile policies, but that is not our task today. For purposes of our discussion it is safe to assume that a defense stockpile of critical materials may be needed until fully adequate substitutes are available.

SLIDE 5

In terms of the total economy, however, stockpiles are <u>not</u> the answer. First let us assume that disruption of critical material supply is not caused by armed conflict, but by political action on our part or on the part of those who would supply us with the material. The results can be the same as we saw recently in the cobalt crisis -- high prices and short supply.

The national response is to use technically adequate substitutes, even those that under normal conditions would not be economical. It would be unwise to invade a defense stockpile in response to political actions, except for strictly defense requirements.

I would like to make the point here that cartels involving critical metals are much less likely if adequate substitutes have been identified and well publicized.

SLIDE 6

Now let us examine the goal of economic substitution -- and the various steps in this process that are going on all the time. First of all, the substitute material must exhibit acceptable properties at a lower cost, or improved properties at a cost that can be justified in terms of a better product that can be sold at a premium, or in terms of lower processing cost. It is important to factor into the total cost of substitution the cost of innovation -- that is the cost of several steps required to demonstrate the adequacy of a substitute -- as well as the amortized cost of transition from the standard material to the substitute material.

SLIDE 7

Innovation is classically based on these four steps -- foundation, invention, demonstration and implementation. Let us examine each of these in terms of development of a substitute alloy.

SLIDE 8

First there must be the foundation of basic metallurgical knowledge. Without this, innovation cannot be expected to be successful except in the case of a few "lucky breaks", and such technical gambling is very costly.

For purposes of material substitution, supplemental knowledge may be required to meet specific requirements. It is usually not possible to design an alloy on the basis of metallurgical theory alone -- the response to environment, such as heat or corrosion, for example, often cannot be predicted.

SLIDE 9

Invention is the next step, after considering the requirements of a material in terms of the knowledge available. Here we are not talking about revolutionary invention -- the great inspirations that create new industries, but evolutionary invention -- organized to take advantage of available knowledge to create a competitive advantage or to respond to a specific need. Materials substitution is based on evolutionary invention and results in laboratory demonstration that the new material exhibits the required properties.

SLIDE 10

Successful materials development requires several levels of demonstration beyond the laboratory -- field trials of small heats, followed by full-scale production trials, and finally rigorous product qualification.

Implementation usually overlaps demonstration in a successful materials development. Marketing often begins at the field trial stage and, to be successfully implemented, the new material must have product acceptance by one or more producers and several consumers.

SLIDE 11

Once a proven substitute material has been developed, there is a considerable transitional cost before the theoretical savings can be realized. This slide describes the various initial costs that must be incurred. The cost of production trials, product qualification and marketing have already been discussed. In addition are the costs of field service to help customers with the transition, and the inevitable double inventory of standard and new material during the transition.

Whether the alloy substitution is for economic or strategic reasons, the steps are the same. In the case of economic substitution the net result is a realized savings at some future time, as shown here. In the case of a strategic substitution, the substitute alloy may never result in a savings over an existing alloy. In such a case the stimulus for the development cannot be expected to come from the private sector.

Now let us examine the technical considerations of alloy substitution.

METALLURGY OF SUBSTITUTION

SLIDE 12

As shown in this slide of the periodic table, the four transition elements upon which this session is focused are neighbors of the four critical metals titanium, chromium, cobalt, and tantalum.

However, it is not direct substitution of one element for another that we are considering, because the essential factor is that the substitute provides the important functional properties of the original. For example, yesterday we heard that the substitution for chromium in austenitic stainless steels is not its replacement with, say, molybdenum; rather it is another alloy combining several metallic elements including manganese and aluminum. Such a substitution may require a long development and transition time. Other substitutions under development to reduce the level of chromium in stainless steels by increasing the molybdenum level have already reached the production trial stage and therefore require a shorter transition time. The substitute must perform the same function as the original, only if the substitute has the same properties as the original is the replacement technically adequate.

SLIDE 13

A very limited number of applications require a material with only one critical property. In every other case, a hierarchy of property requirements must be realized by the alloy. This makes the substitution more challenging, but far from impossible. The expanded use of the four versatile alloying elements which we are about to consider offers many opportunities to achieve a broad range of properties in various alloy systems. It is the multitude of properties that vanadium, nickel, molybdenum and tungsten impart to alloys that make them so attractive as substitutes.

When a designer makes a material selection, he considers more than the required properties of the material. The metallurgy of substitution also consists of the processing route taken to build the final product. Two levels of change may be identified relative to the processing of an alloy.

SLIDE 14

First is the process employed to make the alloy. There is no reason to expect that a substitute alloy will be made in the same manner as the original. Existing processes may require modification to be compatible with the substitute alloy, or the existing process may be completely incompatible. But an opportunity exists that by changing the original process, the critical metal may be conserved and the necessity for substitution thereby mitigated. The example of the development of argon-oxygen decarburization and its attendant improvement in yield of chromium comes immediately to mind.

The second implication for processing is to use processing itself to conserve material. Recent advances in such processes as thermomechanical treatments, near-net shape forming, ion implantation, and laser glazing permit the manufacture of novel new metallurgical microstructures. Further developments in these and other areas are certain to open new opportunities for processing as a means for conserving materials and alloying elements.

STATISTICS OF CURRENT USAGE

SLIDE 15

The subject of this session is, however, the expanded use of metals with domestic or near-domestic sources as substitutes for

critical metals. In closing this introduction to the session I shall briefly highlight some of the statistics of current usage of the four elements of interest. In the slides which follow I have used U.S. Bureau of Mines data for 1979. I expect that the five speakers will elaborate on these data and provide even more current information.

SLIDE 16

The four alloying elements have long been used by alloy designers in the United States. This fact has led to the many major end uses, illustrated in this slide. While there is some overlap in the categories and some unexpected gaps, the important point is the breadth to which each element is used in the current U.S. economy. The four elements are used principally in the producing sector of the economy rather than in consumer goods. It is this sector which will largely be called upon to absorb the effects of any reduction in critical metal supply, and the familiarization of this sector with the domestic and near-domestic substitutes assures a minimum of disruption during required alloy changes.

Because the four alloying elements have long-established uses, large business enterprises have been built to produce, refine and distribute them. The two elements whose use in dollar terms are greatest, nickel and molybdenum, have been aided in their growth

by active metallurgical research and development for many years. The principal companies involved in the vanadium and tungsten businesses have more recently begun similar programs of technical support. Thus, the four domestic and near domestic alloying elements have a distinct further advantage of a fully constructed business infrastructure plus metallurgical expertise to facilitate expanded applications.

SLIDE 17

Most of the U.S. consumption of molybdenum and vanadium, and substantial percentages of nickel and tungsten is in the steel industry. This slide illustrates, as the one before, the wide range of intermediate products into which the elements are already incorporated. The specific applications reported here for 1980 represents only one particular set of technological and economic conditions. As the country's economy changes and, importantly, as technology advances, the distribution of usage by intermediate product changes. Such changes are an ordinary part of the metals business, so increased reliance on these metals as substitutes for the critical metals will not constitute a unique situation. I'm sure the speakers to follow will elaborate further on the directions that the domestic and near-domestic alloying elements are expected to take.

SLIDE 18

This slide is intended to illustrate the relative sizes of the production and use of the four metals in the United States. Only in molybdenum is the United States presently self sufficient. The share of imports of nickel and tungsten from Canada is very large, however, and when this source is included the net import reliance is reduced to the range of 22 to 35 percent. This may appear to be an unacceptably high reliance on imports but the reserves of these four metals in the U.S. and near-domestic areas are very large.

SLIDE 19

Just a reminder that according to the Bureau of Mines a Reserve Base is a "resource that meets minimum physical and chemical requirements of current mining and production practice" and is likely to be economically available within a long-term planning frame. It included identified reserves that are both currently economic and marginally economic.

SLIDE 20

When the reserve bases of the four metals are considered it is obvious that the metals are plentiful domestically and near-domestically. Furthermore, there is no threat that the supply of these metals may be rapidly depleted if their use expands markedly. The four are truly abundant in North America and can be relied upon for many years of future utility.

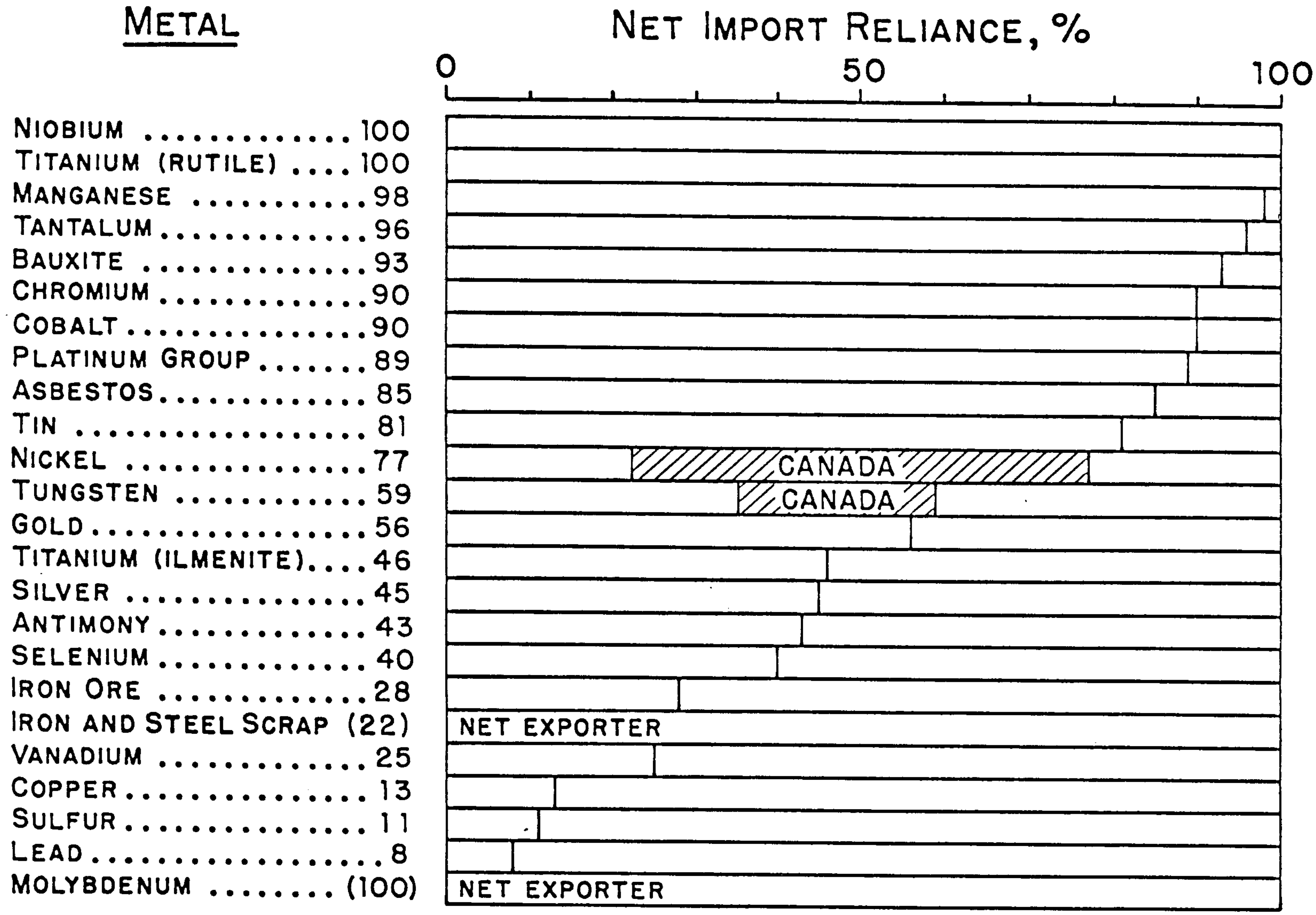
SLIDE 21

A combination of factors supports the notion that critical metals may find molybdenum, nickel, tungsten, and vanadium as excellent substitutes. These factors include: the natural abundance of the four, their versatility as alloying elements, their long-standing use by the technological community, and the existance of a business infrastructure for the mining, refining, distribution, and technological development of each. It is worth repeating that private industry can be expected to pursue substitutions only if there is potential economic gain. Efforts to find substitutes for metals considered critical, but which are currently readily available, will require stimulus from the federal government. Our attention will now be turned to the technological opportunitites that each of the four metals offers. The speakers will be focusing on two major areas.

SLIDE 22

First, they will provide you with greater detail on the metal statistics of molybdenum, nickel, vanadium and tungsten. And secondly, they will cite progress which has already been achieved in the effective use of molybdenum, nickel, vanadium, and tungsten to reduce our dependence on chromium, cobalt, titanium, and tantalum.

UNITED STATES RELIANCE ON IMPORTED MATERIALS



SLIDE 1

ALLOY SUBSTITUTION

- ECONOMIC
- STRATEGIC

SLIDE 2

FACTORS INVOLVED IN STRATEGIC SUBSTITUTION TO REDUCE DEPENDENCE ON EXTERNAL SUPPLY

- RELIABILITY OF EXTERNAL SUPPLY (GOOD EXCEPT FOR A FEW METALS)
- EFFECT OF DISRUPTION ON
  - DEFENSE CAPABILITY
  - TOTAL ECONOMY

SLIDE 3

CRITICAL MATERIALS
AFFECTING DEFENSE CAPABILITY

TECHNICALLY ADEQUATE SUBSTITUTES MAY NOT BE AVAILABLE, BUT ...

- TOTAL MATERIAL REQUIRED IS SMALL
- STOCKPILE PROGRAM FEASIBLE

SLIDE 4

MATERIALS DISRUPTIONS
vs
TOTAL ECONOMY

- POLITICAL ACTIONS:

  - HIGH PRICE
  - SHORT SUPPLY

- NATIONAL RESPONSES:

  - USE TECHNICALLY ADEQUATE SUBSTITUTES EVEN IF UNECONOMIC

  - DO NOT USE DEFENSE STOCKPILE

SLIDE 5

ECONOMIC SUBSTITUTION

- ACCEPTABLE PROPERTIES
- LOWER TOTAL COST MUST INCLUDE:
  - COST OF INNOVATION
  - AMORTIZED COST OF TRANSITION

SLIDE 6

STEPS
TO INNOVATION

- FOUNDATION
- INVENTION
- DEMONSTRATION
- IMPLEMENTATION

SLIDE 7

FOUNDATION

- AVAILABLE BASIC METALLURGICAL KNOWLEDGE
- SUPPLEMENTAL KNOWLEDGE TO MEET SPECIFIC REQUIREMENTS OF SUBSTITUTION

SLIDE 8

INVENTION

- REVOLUTIONARY -- NOT IN RESPONSE TO SPECIFIC NEED, BUT CAN CREATE NEW INDUSTRIES
- EVOLUTIONARY -- ORGANIZED TO CREATE COMPETITIVE ADVANTAGE OR TO RESPOND TO SPECIFIC NEED
- MATERIALS SUBSTITUTION BASED ON EVOLUTIONARY INVENTION, AND RESULTS IN LABORATORY DEMONSTRATION OF ADEQUATE PROPERTIES

SLIDE 9

DEMONSTRATION

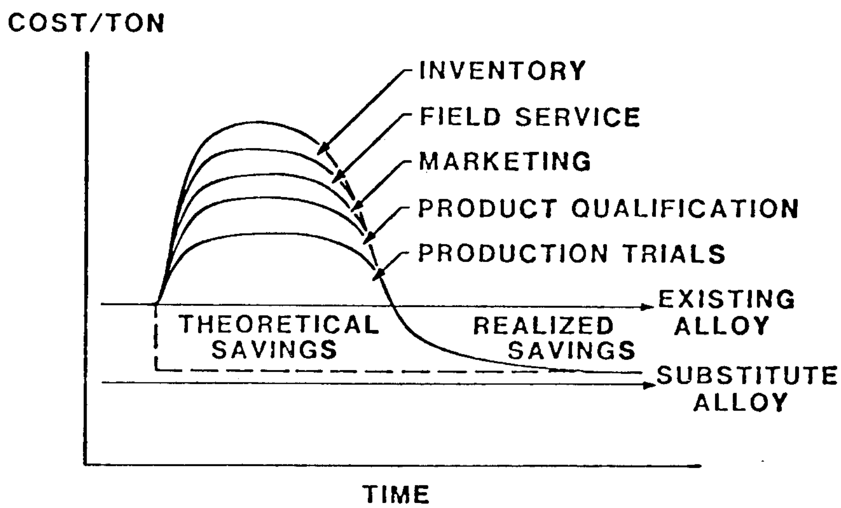
- FIELD TRIALS
- FIRST FULL-SCALE PRODUCTION TRIALS
- PRODUCT QUALIFICATION

IMPLEMENTATION

- MARKETING
- PRODUCT ACCEPTANCE

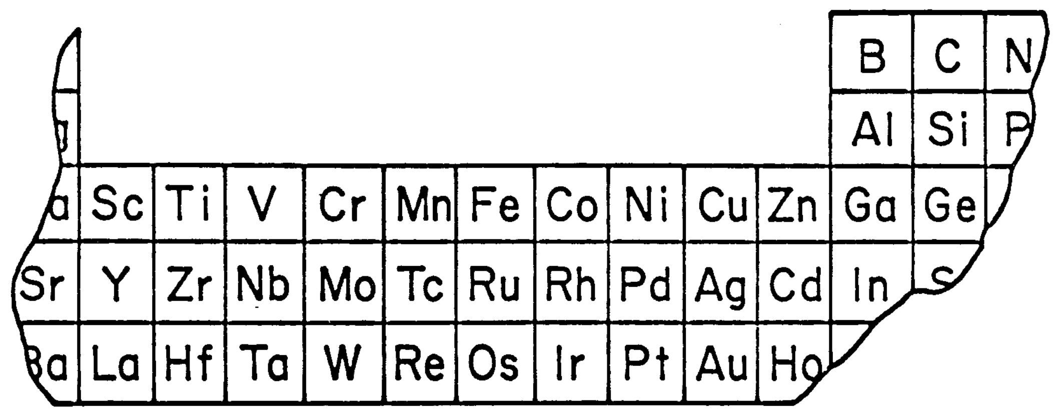
SLIDE 10

ECONOMICS OF TRANSITION IN ALLOY SUBSTITUTION



SLIDE 11

SOURCE: DAVISON


B C N
Al Si
Sc Ti V Cr Mn Fe Co Ni Cu Zn Ga Ge
Sr Y Zr Nb Mo Tc Ru Rh Pd Ag Cd In
La Hf Ta W Re Os Ir Pt Au

SLIDE 12

METALLURGY OF SUBSTITUTION IN ALLOY SYSTEMS

- RELATIVELY EASY WHEN CONSIDERING ONE PROPERTY AT A TIME

- MORE DIFFICULT TO PROVIDE ALL REQUIRED PROPERTIES:

  - STRENGTH AT ROOM AND SERVICE TEMPERATURE
  - TOUGHNESS AT ROOM AND SERVICE TEMPERATURE
  - FATIGUE RESISTANCE
  - CORROSION RESISTANCE
  - WELDABILITY
  - FORMABILITY
  - ETC.

SLIDE 13

IMPLICATIONS FOR PROCESSING

- MODIFY PROCESSING TO OPTIMIZE ALLOY CHANGES
- USE NEW PROCESSES TO CONSERVE ALLOYS

SLIDE 14

STATISTICS OF CURRENT USAGE

- MOLYBDENUM
- NICKEL
- VANADIUM
- TUNGSTEN

SLIDE 15

MAJOR END USE DISTRIBUTION IN THE U.S.
(Percent in 1979)

	Mo	Ni	V	W
Machinery and Metalworking	32		30	77
Transportation	22	24	34	10
Oil and Gas Industry	17			
Chemical Industry	13	14	5	
Electrical Industry	8	13		4
Construction		9	19	
Consumer Goods		16		
Lamps and Lighting				6
Other	8	24	12	3
	100	100	100	100
Approximate Value, Million 1979 $	500	1470	94	200

SLIDE 16

U.S. CONSUMPTION BY INTERMEDIATE PRODUCT
(Percent in 1979)

APPLICATION	ELEMENT			
	Mo	Ni	V	W
STEELS				
Carbon and HSLA	8	-	53	-
Stainless and Heat Resisting	15	36	-	2
Full Alloy	40	10	23	1
Tool	6	-	12	10
CAST IRONS	5	2	-	-
SUPERALLOYS	8	8	-	4
OTHER ALLOYS	2	27	9	4
MILL PRODUCTS	7	-	-	22
CHEMICALS AND CERAMICS	6	-	1	3
PLATING	-	15	-	-
CARBIDES	-	-	-	52
MISCELLANEOUS AND UNCLASSIFIED	3	2	2	2
	100	100	100	100
TOTAL 1979 USE, MILLION LBS	74	543	15.5	25.5

SLIDE 17

1979 U.S. PRODUCTION, IMPORTS AND EXPORTS
(IN MILLION POUNDS OF METAL)

	Mo	Ni	V	W
Mine Production	141	28	12.6	6.6
Imports for Consumption	2	390	4.6	11.0
Exports	68	42	2.8	1.4
Net Import Reliance, %	0	77	25	59
Net Import Reliance Excluding Canada, %	0	22	25	35

SLIDE 18

RESERVE BASE
(AS DEFINED BY U.S. BUREAU OF MINES)

"RESOURCE THAT MEETS MINIMUM PHYSICAL AND CHEMICAL REQUIREMENTS OF CURRENT MINING AND PRODUCTION PRACTICES"

- INCLUDES CURRENTLY ECONOMIC (RESERVES) AND MARGINALLY ECONOMIC (MARGINAL RESERVES)

SLIDE 19

RESERVE BASE
(IN MILLION POUNDS OF METAL)

COUNTRY OR REGION	Mo	NI	V	W
United States	9,100	5,400	230	275
Canada	1,100	17,200	-	535
Mexico	-	-	-	44
Chile	5,400	-	300	-
Other South America	500	-	-	127
Pacific		30,000	400	410
Europe	-	-	-	264
Republic of South Africa	-	-	17,200	-
Other Market Economy Countries	600	56,000	700	180
Central Economy Countries	2,000	16,400	16,000	3,700
World Total	18,700	125,000	34,800	5,600
1979 U.S. Consumption	74	543	15.5	25.5

SESSION GOALS

- PROVIDE MORE DETAIL ON METAL STATISTICS
- CITE PROGRESS IN EFFECTIVE SUBSTITUTION OF
  Mo, Ni, V, W
  TO REDUCE DEPENDENCE ON
  Cr, Co, Ti, Ta

SLIDE 22

SUPPORT FOR SUBSTITUTION

- PRIVATE INDUSTRY IF CURRENT OR POTENTIAL ECONOMIC GAIN
- FEDERAL GOVERNMENT IF MATERIALS DISRUPTION POSSIBLE, BUT NO ECONOMIC GAIN ENVISIONED

SLIDE 21

MOLYBDENUM AS A SUBSTITUTE FOR CRITICAL METALS

Ralph M. Davison
Climax Molybdenum Co.

MOLYBDENUM AS A SUBSTITUTE FOR CRITICAL METALS

Ralph M. Davison*

INTRODUCTION

Molybdenum is readily available in ample supply from domestic and near-domestic sources. It is technically versatile and the technology of its utilization is well known. Molybdenum can make a major contribution to reducing dependence of this nation on critical metals.

SUPPLY AND DEMAND FOR MOLYBDENUM

Since its first use for armor and armaments in World War I, molybdenum has grown to be an important alloy element in use worldwide in a wide diversity of products. As shown in Table 1, it is used in all industrialized countries with the extent of its use in rough correlation to the degree of industrial development. Growth in the use of molybdenum has outpaced overall economic growth for over fifty years, and it is expected that it will continue to do so for the foreseeable future. Worldwide requirements for molybdenum are presently slightly over 200 million pounds per year except in recession periods, with the United States requirement being roughly 70 million pounds.

Molybdenum is a product of the Western hemisphere, as shown in Table 2, with a predominant concentration in the United States and with Canada having the second largest share. Commercially, molybdenum is mined either as a primary product or as a by-product or co-product of copper mining. Mine capacity has increased rapidly over the last five years in response to market demand. Most of the increase has been in new primary mines, a factor that will assure molybdenum supply in the future. As shown in Table 3, the dominant position of the United States, and even more the combined dominance of the United States and Canada, will increase in the future. The tight supply of the late 1970's prompted new mine development which will result in

*Dr. R.M. Davison is Director of Metallurgical Development, Climax Molybdenum Company, P.O. Box 1568, Ann Arbor, MI 48106

an increase of about 30 percent in mine capacity by 1983. These new mines are all in North America, owned and operated by commercial companies, and are in most cases, primary molybdenum mines. As indicated in Table 4, these trends are expected to continue as the properties known to exist and to be in evaluation are similar in nature and location.

APPLICATIONS OF MOLYBDENUM

Molybdenum is a highly versatile and effective alloy element. In additions under 1 percent, but typically between 0.2 and 0.4 percent, molybdenum provides hardenability in steels and irons. Not only is molybdenum a highly efficient hardenability agent in terms of weight or atomic percent, at the same time it enhances the toughness of the hardened steel. Molybdenum's contribution of resistance to tempering and to temper embrittlement allows the hardened steel to be used at elevated temperatures without degradation of properties. Molybdenum provides strengthening both through solid solution strengthening and through precipitation hardening in steels and alloys. Molybdenum in amounts typically ranging from 0.5 to 6 percent, but as high as 26 percent enchances the corrosion resistance of steels and alloys. Molybdenum and molybdenum-base alloys have found many important applications as a refractory metal utilizing high temperature properties, high electrical and thermal conductivity, and corrosion resistance. In addition to its metallurgical applications, molybdenum is also used in a wide range of chemical applications, including catalysts, pigments, lubricants, and corrosion inhibitors, accounting for up to one tenth of total molybdenum demand.

This wide range of technical benefits leads to distribution of molybdenum usage over a wide variety of intermediate products, as shown in Table 5. The category of low alloy steels may be further broken down into carburizing steels, elevated temperature steels, oil country tubular goods, and other wrought steels, each of these categories being large enough to stand separately.

An important aspect of this diversity is that most industries with the need of a substitute for a critical metal have already had experience with molybdenum. Consequently, suvstitution of molybdenum is most frequently an extension of known technology without the difficulties of opening completely new technology.

In contemplating an effort to decrease dependence on critical metals, it should be recalled that during World War II, it was at the direction of the War Materials Board that the "NE-steels" (National Emergency steels) were developed. These steels were based upon utilization of molybdenum and the "triple-alloy" concept to munimize the total use of critical metals. Subsequently, those steels which were both technically and economically justified were accepted as standard SAE grades and are still in use today.

PROCESS OF MATERIALS SUBSTITUTION

For over fifty years molybdenum has been the focus of a research and development effort aimed at identifying potential applications of molybdenum and bringing them to commercial reality. The growth of molybdenum at a rate exceeding that of total economic growth over that period is testimony in support of directed innovation. The four steps of innovation as cited in the keynote presentation are Foundation, Invention, Demonstration, and Implementation. Utilizing the foundation of all metallurgical knowledge to which this effort makes its own contribution, the evolutionary invention of new applications of molybdenum has gone forward. The laboratory demonstrates that new alloys can meet specified technical goals, but the real successes of Demonstration are those achieved in partnership with individual producers of the intermediate product. The production and processing of a commercial-size trial heat and its subsequent utilization with typical field practice are the essential elements of Demonstration. Climax Research and Development then stimulates Implementation through assistance with formal organizational acceptance and specification, through assistance in development of

field practice, and through screening tests to minimize the risk and cost of substitution.

All projects carried through this process are economically justified. If Invention produces an interesting technical concept but one that cannot win the economic competition of the marketplace, it is recorded and set aside. Demonstration and Implementation require the cooperation and commitment of an intermediate product producer. Without economic incentive there is not likely to be any commercialization. However, it is possible to note instances where the risk associated with critical metal disruption is high enough that Demonstration of a new alloy will be carried out even when the substitution is known to be currently uneconomic. These observations are important, for while economic competition is an efficient and powerful engine for economically justified innovation, an alternative incentive or mechanism must be provided for anticipatory development of currently uneconomic technology.

USE OF MOLYBDENUM AS A SUBSTITUTE FOR CRITICAL METALS

The remainder of this discussion will concentrate on actual substitutions for critical metals, including those presently in progress, those that could easily become economic, and those that are technically feasible but unlikely to be economically justified. Substitution in its broad definition can include redesign of whole systems, but for the present discussion it will be defined narrowly to mean identification of an alternative metal meeting all specifications with only minor accomodations of design. It will be assumed that it is necessary to deal with only one critical metal at a time, and that the problem is a supply limitation or an extraordinary price increase, e.g., more than four to tenfold. The discussion will not seek the complete resolution of the problem of any one critical metal but rather to indicate the role of molybdenum in partial substitution for the critical metal.

COBALT

Cobalt is an ideal first example because it has recently experienced a period of sharply reduced availability and abruptly increased price with an uncertain price future. The rapid response of users in developing substitutes and reducing their dependence on cobalt demonstrates the power of the mechanism of economically justified substitution.

Cobalt is an important element, serving as a base for high temperature creep resistant alloys, hardfacing and wear resistant alloys, and high temperature spring and bearing alloys. As an alloy addition, cobalt is used in high speed and tool steels for hot hardness and temper reisistance, in tungsten carbide tool materials as a binder, and in alloys with special magnetic, electrical, or mechanical properties.

The use of cobalt in superalloys can be reduced through a shift toward the nickel-base alloys. Extensive rebalancing of the alloy composition is necessary as the strenthening by geometrically close packed phases such as carbides must be sacrificed. Molybdenum additions for solid solution strengthening and enhanced γ'-strengthening are part of the resolution of the multifaceted problem of matching strength, creep resistance, oxidation resistance, corrosion resistance, and fabricability. A new alternative to rebalancing within the conventional superalloy systems is the new Ni-Mo-Al superalloy. Even with a strong commercial incentive, the progress of substitution is slow because of the high risk associated with a failure and the expense of alloy testing and qualification.

Near the opposite extreme is the use of cobalt in hardfacing where competition is based on performance and cost rather than industry code, and substitutions can be readily made when a favorable relationship is demonstrated. The surge in cobalt prices brought research programs in progress for several years to immediate attention. The result was rapid commercial demonstration and implementation. A number of cobalt-free alternatives are now commercially available, such as the

Climax-developed XN930C (Ni-9% Mo-30% Cr-2.0% C) which meets the performance specifications of the cobalt-base Stellite 6.

Although combinations of chromium, molybdenum, and tungsten may be used to produce the critical properties of highly alloyed high speed and tool steels, cobalt is necessary if the conventionally produced alloys are to be forgeable. The cobalt supply situation has accelerated development of alternative processing techniques that avoid the necessity of using cobalt. For example, Crucible Steel has utilized powder metallurgy techniques to produce CPM Rex 25[T1] (6.5% Mo) and 20 (10.5% Mo) which are cobalt-free alternatives to T-15 (5% Co) and M-42 (8% Co).

MP-35N[T2] (35% Co) and Elgiloy[T3] (40% Co) have performed satisfactorily for springs and down-hole tooling equipment for sour gas wells. When the extremely several environments of the ultra-deep Mississippi sour gas wells (over 25,000 feet) were encountered, MP-35N was considered as a candidate for casing and tubing. The radical increase in cobalt price necessitated the qualification of cold worked nickel-base C-276 (16% Mo) for this application.

Finally, for cobalt, it is possible to cite a cobalt-base alloy highly resistant to substitution. Although a number of Cr-Mo stainless steels or nickel-base alloys might reasonably be considered on their techical merit. Cobalt-based Vitallium[T4] which is used for prothesis of human bone is unlikely to change. With immense liability consequences, demonstration, let alone implementation, is a step not lightly undertaken.

CHROMIUM

It is difficult to overstate the importance of chromium as an alloy addition and the economic disruption that would accompany an interruption of chromium supply.

[T1] Trademark of Colt Industries, Crucible Steel Divison.

[T2] Trademark of E.I. du Pont de Nemours.

[T3] Trademark of Elgiloy Company, division of American Gage and Machine Company

[T4] Trademark of Howmet Corporation.

Chromium provides hardenability, corrosion resistance, oxidation resistance, and wear resistance, as well as serving in plating, refractories, and chemical applications at modest cost to the user. Recent steelmaking advances such as the argon-oxygen decarburization process, have only encouraged greater reliance on chromium. Certainly its unique technical contributions necessitate a stockpile of chromium, in an appropriate form, to meet the strategic needs of the nation. But the dependence on chromium is so broad economically, that substitutes must be developed if the nation is to realize political freedom of action.

One application of chromium is easily replaced. At its present price and availability, chromium is frequently used as a hardenability addition for steels and irons. Even now through "price book metallurgy" the switch from the Cr-Ni SAE 9300 (1-1.4% Cr) steels to the Ni-Cr-Mo EX-55 (0.4-0.65% Cr) is economically justified while providing improved hardenability and toughness. Although not presently justified economically, a 2Ni-1Mo steel has been carried through full-size commercial demonstration as a competent substitute for EX-55. This demonstration was undertaken by a tooling company to provide insurance against any future chromium disruptions. It demonstrates that the hardenability applications of chromium are strictly a question of economics and that substitution would be readily achieved.

Substitutions are much more difficult to achieve when it is necessary to change to a new producing industry and develop new application practice. For example, Si-Mo nodular cast iron can be considered as an alternative to Cr-Mo steel in a number of heat resistant applications. However, even in the cases that are economically justified, the mechanics of transition are almost unsurmountable without the impetus of real crisis.

The definition of a stainless steel is founded on the passive film characteristic of steels containing in excess of 12 percent chromium. Although alternative alloy systems may be suggested, none have the utility or ease of production, fabrication, and application that are associated with the common stainless steels. Molybdenum is well known to stabilize the passive film against localized break down, particularly in the presence of chlorides. There is even a rule of thumb that molybdenum is three times more powerful than chromium in terms of weight percent in its effect on corrosion resistance. However, this favorable relationship describes the synergistic relationship of chromium and molybdenum used in their customary proportions. While use of additional molybdenum will permit reduction of chromium content, the molybdenum addition rapidly becomes disproportionately larger than the chromium reduction and the total substitution is limited by phase instability. However, one example of reduced chromium requirement is the alternative of using the austenitic stainless steel AL-6X[T5] (20Cr-6Mo-24Ni) for seawater condenser tubing in place of the ferritic stainless steel AL 29-4C[T5] (29% Cr-4% Mo).

TANTALUM

Tantalum is a metal already so expensive that it is difficult to consider economic incentives for further substitution. Tantalum is used sparingly to utilize its extraordinary corrosion resistance in certain chemical environments, its compatability with human tissue, and its highly stable carbide as a strengthener of high temperature superalloys. In a few of the corrosion applications of tantalum, molybdenum metal may be considered as a substitute. In conventional superalloys, the contribution of tantalum to high temperature creep resistance can be replaced

[T5]Trademark of Allegheny Ludlum Steel Corporation.

by a combination of Nb, Ti, and Hf carbide strengthening and Mo and W solid solution strengthening. The development of the new generation of Ni-Mo-Al superalloys and the application of rapid solidification rate (RSR) technology offer the potential for reducing dependence on this critical metal in the future.

TITANIUM

Titanium and titanium-base alloys are used structurally when a high strength-to-weight ratio is desirable as in the case of airframes. Titanium provides excellent corrosion resistance in a wide range of chemical environments, including seawater. Titanium is employed for its reactivity with carbon and nitrogen as a stabilizer of stainless steels. In microalloy additions, titanium has been used for HSLA steels.

Molybdenum is able to offer economically competitive substitutes for titanium in most of its corrosion applications. For example, there is presently an active competition of molybdenum-containing stainless steels (29Cr-4Mo, 26Cr-3Mo-2Ni, 20Cr-6Mo-24Ni) with titanium for power plant condenser tubing where seawater is the coolant. Matching the excellent strength-to-weight ratio of titanium and its alloys is more difficult. However, alternatives are known, including a few that use molybdenum such as 13-8Mo (13% Cr-8% Ni-2% Mo-1% Al), a precipitation hardened stainless steel. In HSLA steel, transformation-controlled steels containing molybdenum or vanadium may be used as satisfactory substitutes for the titanium containing steels.

CONCLUSIONS

Molybdenum has been, is, and will remain a domestic material that is readily available in supply adequate to handle its present and future potential applications. Molybdenum is a technically versatile element with widely diversified applications

and years of industrial experience demonstrating its ease of utilization. More than fifty years of focused research and development have placed molybdenum in a highly advanced state of economic substitution in all steps of the innovation process: Foundation, Invention, Demonstration, and Implementation. Associated with the progress of economic substitution, the status of substitution not presently economic is also highly advanced, with many alternative metals lacking only implementation. Molybdenum technology is a powerful and versatile tool for reducing dependence on critical metals.

Table 1

MOLYBDENUM CONSUMPTION BY GEOGRAPHIC AREA*
(Million Lb Molybdenum)

	1976	1977	1978	1979	1980**
United States	57	60	69	71	60
Western Europe	70	70	72	75	66
Eastern Bloc	15	17	22	22	18
Japan	25	24	25	25	26
Other	10	11	12	12	12
Total	177	182	200	205	182

*Consumption of molybdenum produced in Western World.

**Preliminary estimates.

Table 2

WESTERN WORLD MOLYBDENUM PRODUCTION
(Million Lb Molybdenum)

By Geographic Area

	1976	1977	1978	1979	1980*
United States	113	123	131	144	151
Canada	31	33	32	22	32
Chile	24	24	28	30	30
Other	3	3	3	4	5
Total	171	183	194	200	218
By Type of Mine					
Primary	92	100	106	106	123
By-Product	79	83	88	94	95
Total	171	183	194	200	218

*Preliminary estimates.

Table 3

SCHEDULED NEW MOLYBDENUM MINES

Mine	Country	Company	Estimated Startup	Est. Annual Production (Million Lb)
Continental	USA	Anaconda	1981	7-8
Highmont	Canada	Teck	1981	6-8
Kitsault*	Canada	AMAX	1981	9-10
Nevada Moly*	USA	Anaconda	1982	12-15
Thompson Creek*	USA	Cyprus Mines	1983	15-21
Goat Hill*	USA	Molycorp	1983	18-20

*Primary mines.

Table 4

MOLYBDENUM PROSPECTS UNDER STUDY

Mine	Country	Company	Feasible Startup	Est. Annual Production (Million Lb)
Adanac	Canada	Placer	1983	6
Mt. Tolman	USA	AMAX	1984	19-23
Bingham Expansion	USA	Kennecott	1985	7**
Boss Mountain Expansion*	Canada	Noranda	1988	8**
Mt. Emmons*	USA	AMAX	1989	30
Quartz Hill*	USA	U.S. Borax	1990	26

*Primary mines.

**Estimated additional production.

Table 5

MOLYBDENUM CONSUMPTION BY INTERMEDIATE PRODUCTS
(Percent of Total Consumption)

Intermediate Product	1977	1978	1979	1980
Low Alloy Steels	49	47	46	46
Stainless Steels	20	20	20	21
Tool Steels	9	9	10	10
Chemicals & Lubricants	8	9	9	8
Cast Irons & Steels	7	7	7	6
Molybdenum Metal	3	4	5	5
Superalloys	3	3	3	3
Other	1	1	0	1
Total	100	100	100	100

NICKEL AS A SUBSTITUTE FOR METALS IN CRITICAL SUPPLY

Robert J. Johnson
International Nickel Co.

NICKEL AS A SUBSTITUTE FOR METALS IN CRITICAL SUPPLY

R. J. JOHNSON
MANAGER, SALES DEVELOPMENT
THE INTERNATIONAL NICKEL COMPANY, INC.
ONE NEW YORK PLAZA
NEW YORK, N. Y. 10004

WORKSHOP ON CONSERVATION AND SUBSTITUTION
TECHNOLOGY FOR CRITICAL MATERIALS

VANDERBILT UNIVERSITY
NASHVILLE, TENNESSEE
JUNE 15-17, 1981

U.S. DEPARTMENT OF COMMERCE, NATIONAL
BUREAU OF STANDARDS AND U.S. DEPARTMENT
OF INTERIOR, BUREAU OF MINES

Eighty years of research, production and field experience have taught us many things about nickel, including the technical rationale supporting a yearly world consumption of 1.2 billion pounds. Accordingly, we are very pleased to consider with you some technological opportunities for increasing the use of nickel to replace other metals in limited supply. I refer specifically to chromium, cobalt and titanium. But before we discuss these matters, let me present two brief reminders:

Slide No. 1 - Worldwide Commercial Sources of Nickel

We are fortunate that nickel occurs naturally on every continent. This circumstance favors uninterrupted supply despite recurring political upheavals around the world. In the longer view, however, we must appreciate that all metals found on Spaceship Earth will in time be in critical supply, so our consumption and conservation practices must constantly be improved. Just now, the United States and its neighbors are in a favorable situation with respect to nickel availability.

Slide No. 2 - U. S. Primary Nickel Consumption by End-Use Markets

Nickel has proven to be a hugely versatile element, and we estimate that today it is used in some 3000 alloys, chemical compounds and plating systems for applications numbering in the tens of thousands. This graph shows, by

MARKET SECTOR, WHERE THE U. S. CONSUMED 325 MILLION POUNDS OF NICKEL IN 1980. STAINLESS AND ALLOY STEEL TOGETHER LEAD WITH 43% OF THE MARKET. NEXT IS COPPER AND NICKEL-BASE NONFERROUS METALS FOLLOWED BY PLATING AND CHEMICALS, THEN FOUNDRY. LET'S EXAMINE SOME CONSERVATION OPPORTUNITIES IN EACH OF THESE MARKET SECTORS, BEGINNING WITH STAINLESS STEELS. (SLIDE OFF)

DOMESTIC CONSUMPTION OF THESE REMARKABLE MATERIALS HAS CLIMBED IN RECENT YEARS TO OVER ONE MILLION TONS ANNUALLY - 1.2 MILLION TONS IN 1980. SEVENTY PERCENT OF THIS IS NICKEL-CONTAINING. STAINLESS STEELS UTILIZED A THIRD OF THE NICKEL AND 70% OF THE CHROMIUM CONSUMED IN THIS COUNTRY LAST YEAR.[1] INDEED, WITH ONE EXCEPTION, APPLICATIONS ARE SO DIVERSE THAT NO SINGLE USE ACCOUNTS FOR MORE THAN ABOUT TWO PERCENT OF TOTAL SHIPMENTS. THE STRONG POSITION OF THESE STEELS IN OUR SOCIETY RESIDES IN TWO TECHNICAL FACTORS:

A) CHROMIUM'S CONTRIBUTION TO CHEMICAL PASSIVITY AND CORROSION RESISTANCE.

B) NICKEL'S EFFECT ON THE ALLOTROPY OF CHROMIUM-CONTAINING IRON, RENDERING IT AUSTENITIC AT ROOM TEMPERATURE AND GREATLY ENHANCING MECHANICAL PROPERTIES AND FABRICABILITY.[2]

SINCE OUR TASK AT THE MOMENT IS TO EXAMINE THE ALTERNATE USE OF NICKEL FOR CHROMIUM, IT IS REASONABLE TO INQUIRE ABOUT CORROSION RESISTANT NON-CHROMIUM MATERIALS WHICH MIGHT BE USED IN PLACE OF STAINLESS STEEL, AND WHETHER STAINLESS STEELS CONTAINING LESS THAN ABOUT 11% CHROMIUM ARE FEASIBLE.

VERY EARLY IN THIS CENTURY, BEFORE STAINLESS STEELS AND AUTOMOBILES ATTAINED COMMERCIAL IMPORTANCE, STEELS CONTAINING AS MUCH AS 30% NICKEL WERE USED FOR THEIR CORROSION RESISTANCE. OUR ARCHIVES CONTAIN REFERENCES TO SUCH ALLOYS IN HARNESS FITTINGS, BOILER TUBES AND VALVES FOR THE SEA WATER SYSTEM INSTALLED BY NEW YORK CITY FOR FIGHTING FIRE.[3]

SLIDE NO. 3 - POSSIBLE SUBSTITUTES FOR STAINLESS STEELS TO CONSERVE CHROMIUM

OF THE COMMERCIALLY AVAILABLE MATERIALS NICKEL SILVER (55CU-18NI-BAL. ZN), WITH EARLY ORIGINS IN CHINESE COINAGE, HAS BEEN POPULAR OVER THE PAST ONE HUNDRED AND FIFTY YEARS FOR HOLLOWARE, ARCHITECTURAL DETAILS, PLUMBING FIXTURES AND ELECTRONIC COMPONENTS. PERHAPS YOU HAVE NOTED ITS USE IN SOME OF THE OLDER BANKS, HOTELS AND OFFICE BUILDINGS.

MONEL* ALLOY 400 (30CU-BAL.NI) AND ITS MODIFICATIONS WERE INTRODUCED EARLY IN THE 1900'S AS NATURAL DERIVATIVES OF CANADIAN ORES CONTAINING BOTH NICKEL AND COPPER. MONEL HAS REMAINED A VERY USEFUL ADDITION TO THE FAMILY OF CORROSION-RESISTANT NONFERROUS ALLOYS SERVING THE CHEMICAL AND PROCESS INDUSTRIES.

ABOUT 1930, THE CUPRONICKELS (70CU-30NI AND 90CU-10NI) MADE THEIR APPEARANCE. THEY NOW FIND MANY APPLICATIONS IN POWER PLANTS AND THE MARINE INDUSTRY WHERE AGGRESSIVE WATERS AND BOIFOULING ARE ENCOUNTERED.

*TRADEMARK THE INTERNATIONAL NICKEL COMPANY, INC.

IN NUMEROUS SITUATIONS, SUBSTITUTION OF THESE NONFERROUS ALLOYS FOR STAINLESS STEELS COULD BE MADE WITH NO PENALTY EXCEPT COST. OTHER ALLOY CHANGES, ESPECIALLY IN THE CHEMICAL INDUSTRY, WOULD REQUIRE MODIFICATION OF PROCESS STREAMS TO MINIMIZE CORROSION.

OF COURSE, A SERIOUS SHORTAGE OF CHROMIUM WOULD GREATLY STIMULATE THE USE OF ALUMINUM, PLASTICS AND MANY KINDS OF COATINGS AS SUBSTITUTES FOR STAINLESS STEELS. (SLIDE OFF).

RECENT INCO WORK FOR THE BUREAU OF MINES SUGGESTS THAT IT MAY BE POSSIBLE TO DEVELOP "STAINLESS" STEELS CONTAINING ONLY 9% CHROMIUM REINFORCED BY ADDITIONS OF NICKEL AND MOLYBDENUM - AND PERHAPS COPPER AND VANADIUM - FOR MILDLY CORROSIVE SERVICE.[4] MUCH REMAINS TO BE DONE ON THIS LINE.

CURRENT RESEARCH TO LEARN MORE ABOUT THE EFFECT OF NICKEL ON PITTING AND REPASSIVATION MAY LEAD TO A BETTER UNDERSTANDING OF AQUEOUS CORROSION AND POSSIBLY TO LOWER CHROMIUM MODIFICATIONS. UNFORTUNATELY, IT APPEARS THAT THESE ATTEMPTS TO REDUCE CHROMIUM MAY ENTAIL INCREASES IN OTHER ALLOYING ELEMENTS, MAKING THE RESULTANT NEW COMPOSITIONS MORE EXPENSIVE.

WE DO SEE SOME PROMISE IN STUDIES DEALING WITH AUSTENITIC STEELS FOR HIGH TEMPERATURE APPLICATIONS IN FURNACES AND VEHICULAR EMISSION CONTROL DEVICES. THIS WORK SUGGESTS THAT SOME CHROMIUM MAY BE SAVED BY ADDITIONS OF SILICON AND ALUMINUM, ALONE OR IN COMBINATION.[5]

PLEASE PERMIT ME TO RESTATE THE FACT THAT CHROMIUM IS UNEQUALLED IN ITS ABILITY TO FORM THE ADHERENT, IMPERVIOUS OXIDE FILMS WHICH PROTECT STAINLESS STEELS FROM AQUEOUS AND HIGH TEMPERATURE ATTACK. MOREOVER, FIFTY YEARS OF RESEARCH HAVE FAILED TO PROVIDE A REPLACEMENT FOR CHROMIUM IN THIS PARTICULAR ROLE. IT SEEMS UNLIKELY, THEREFORE, THAT THIS AUDIENCE WILL SEE COST-EFFECTIVE, METALLIC ALTERNATES FOR THE ESTABLISHED HIGH TONNAGE STAINLESS STEELS.

WE SHOULD TURN NOW TO ALLOY STEELS, AN EIGHT MILLION TON MARKET WHICH CONSUMED 40,000 TONS OF CHROMIUM IN 1980. WE SAW EARLIER THAT 10% OF THE ANNUAL U.S. NICKEL REQUIREMENT GOES INTO ALLOY STEEL, MAINLY FOR IMPROVED STRENGTH AND TOUGHNESS. AS A HARDENER, NICKEL ALONE IS NOT A STRONG PERFORMER; IT DOES BETTER IN COMBINATION WITH SMALL QUANTITIES OF OTHER ALLOYING ELEMENTS SUCH AS CHROMIUM, MOLYBDENUM AND MANGANESE. BECAUSE THE THEORETICAL ASPECTS OF HARDENABILITY AND ALLOY ELEMENT INTERCHANGE ARE WELL KNOWN, I WILL ONLY NOTE THAT LOW NICKEL ALLOY STEELS HAVE A LONG HISTORY BEGINNING WITH THE USE OF 3% AND 5% NICKEL STEELS FOR ARMOR PLATE AND BICYCLE CHAINS BEFORE THE TURN OF THE CENTURY.[(3)] SUCCESSFUL EXPERIENCE WAS THEN TRANSFERRED TO CHAIN DRIVES AND OTHER COMPONENTS FOR CARS AND TRUCKS, AND TODAY NICKEL-MOLYBDENUM AND NICKEL-CHROMIUM-MOLYBDENUM ALLOY STEELS ARE CALLED UPON FOR THE MOST DEMANDING SERVICE IN ALL KINDS OF MACHINERY. THE POINT TO BE MADE HERE IS THAT A VERY LARGE TONNAGE OF CHROMIUM COULD BE SAVED, AT A MARKED COST PREMIUM, BY SUBSTITUTIONS WITH NICKEL. ALL THE REQUISITE TECHNOLOGY IS IN PLACE, AND WE HAVE WARTIME EMERGENCY EXPERIENCE TO DRAW UPON.

Slide No. 4 - Effect of Nickel on the Cleavage Strength of Iron

The explanation for the longstanding preference for nickel alloy machinery steels rests in the unique ability of nickel to retard crack initiation and propagation in ferrous materials. This work by Floreen at our laboratory in Sterling Forest, New York shows the well-known drop in fracture toughness which iron exhibits as test temperature decreases. The beneficial effect of 0.3 to 3.9% nickel on cleavage stress at all temperatures is quite apparent.[6] (Slide Off).

Another opportunity to conserve chromium involves the high strength structural steels. Through a complex mechanism affecting oxidation behavior, nickel permits additions of copper to steel which would otherwise be prohibitive because of the latter's constraints on hot workability.[7] This technology opens the way to greater use of copper in place of chromium for strength and corrosion resistance as in certain ASTM A242 steels or the Inco developed Ni-Cu-Cb steel of ASTM A710.

Outside the 9Ni-4Co steels and the maraging steels (18Ni-8Co-5Mo), which feature very high strength, cobalt is not encountered in commercial alloy grades. Maraging steel usage has been curtailed lately by the high price of cobalt, and a version of the 18Ni-250 alloy containing no cobalt and less molybdenum is being developed by Inco.

TITANIUM SHIPMENTS AMOUNTED TO 54 MILLION POUNDS LAST YEAR, THE MAJOR END-USES BEING AIRCRAFT GAS TURBINES (40%), AIR FRAME COMPONENTS (35%), AND CORROSION RESISTING EQUIPMENT FOR THE POWER, CHEMICAL AND PAPER INDUSTRIES (25%).[3] TITANIUM OFFERS A FAVORABLE COMBINATION OF STRENGTH, WEIGHT, TOUGHNESS, MODULUS OF ELASTICITY AND RESISTANCE TO CORROSION FOR USE IN JET ENGINES. NICKEL STEELS SUCH AS AMS 6415 (1.8NI, 0.8CR, 0.25MO) COULD BE USED IN CRITICAL ROTATING DISC APPLICATIONS, AND AMS 5616 (13CR, 2NI, 3W) FOR BLADES. THESE STEELS WERE SPECIFIED FOR SUCH APPLICATIONS BEFORE TITANIUM WAS ACCEPTED, BUT BOTH REQUIRE CHROMIUM.

SIMILAR CONSERVATION DIFFICULTIES ARE PRESENTED IN THE USE OF LIGHT-WEIGHT ULTRA HIGH STRENGTH STEELS AS ALTERNATES TO TITANIUM IN AIR FRAME STRUCTURES. ALL THE COMMERCIAL HIGH STRENGTH NICKEL ALLOYS SUCH AS 300-M, 9NI-4CO STEEL AND THE MARAGING STEELS CONTAIN CHROMIUM OR COBALT.

HIGH NICKEL ALLOYS SUCH AS INCONEL* ALLOY 625 (21CR-9MO-BAL. NI) AND HASTELLOY+ C-276 (15CR-16MO-3.75W-2.5CO-56NI) COULD REPLACE TITANIUM IN VARIOUS CHEMICAL PROCESS OPERATIONS, BUT YOU WILL PERCEIVE THAT THIS WOULD INCREASE REQUIREMENTS FOR OTHER CRITICAL MATERIALS. HENCE, THERE SEEMS TO BE NO ALLOY FREEWAY IN CERTAIN AREAS OF OUR TECHNOLOGY.

MOVING OVER TO NONFERROUS MATERIALS FOR ELEVATED TEMPERATURE SERVICE, WE OBSERVE THAT WHEN EXPOSED TO

*TRADEMARK THE INTERNATIONAL NICKEL COMPANY, INC.

+TRADEMARK CABOT CORPORATION

AIR AT HIGH TEMPERATURES, NICKEL IS MUCH MORE RESISTANT TO OXIDATION THAN IRON. THE LATTER FORMS THICK OXIDE SCALES WHICH TEND TO CRACK AND FALL AWAY, EXPOSING THE METAL UNDERNEATH TO FURTHER ATTACK. BY COMPARISON, NICKEL TENDS TO FORM THIN, TENACEOUS SCALES WHICH PROTECT UNDERLYING STRATA. ADDITIONS OF CHROMIUM AND ALUMINUM GREATLY AUGMENT THIS BEHAVIOR BY ENTERING THE FORMATION OF COMPLEX SURFACE OXIDES WHICH ARE EVEN MORE PROTECTIVE. ADDITIONALLY, NICKEL IS AN EXCELLENT RECEPTOR FOR ELEMENTS WHICH ADD STRENGTH BY SOLID-SOLUTION HARDENING OR THE CONTROLLED FORMATION AND DISTRIBUTION OF INTERMETALLIC COMPOUNDS. LASTLY, NICKEL DOES NOT COMBINE WITH CARBON THUS RELIEVING METALLURGISTS OF CERTAIN CONCERNS OVER CARBIDES OR PERFORMANCE IN PROCESS STREAMS RICH IN HYDROCARBONS. THESE CHARACTERISTICS HAVE BEEN COMBINED IN A FAMILY OF HIGH NICKEL ALLOYS WHICH FIND MANY IMPORTANT USES IN THE CHEMICAL PROCESS AND AEROSPACE INDUSTRIES.

ONE OF OUR PUBLICATIONS PROVIDES DATA ON SOME 95 WROUGHT AND CAST ALLOYS FOR HIGH TEMPERATURE SERVICE.[(9)] IN REVIEWING THIS INFORMATION FOR CONSERVATION OPPORTUNITIES, I PREPARED THE FOLLOWING LIST OF CONSTITUENT ELEMENTS:

SLIDE NO. 5 - CONSTITUENTS OF HIGH TEMPERATURE ALLOYS

THIS TABLE IS INFORMATIVE AS TO SUPERALLOY DESIGN. NEARLY ALL OF THESE ALLOYS CONTAIN CHROMIUM, USUALLY IN THE RANGE OF 15 TO 20%, AND WE DO NOT SEE MUCH OPPORTUNITY FOR CHANGING THIS. FOR REASONS ALREADY NOTED, IT IS TECHNICALLY

IMPOSSIBLE TO ACHIEVE PERFORMANCE TARGETS, AT LEAST FOR AIRCRAFT ENGINES, WITHOUT CHROMIUM. A SMALL REDUCTION IN THE LEVEL OF CHROMIUM IN SOME ALLOYS APPEARS POSSIBLE, BUT THIS WOULD REQUIRE A REBALANCING OF COMPOSITIONS AND SUBSEQUENT TESTING AND REQUALIFICATION FOR INDUSTRY. WE SEE THIS AS A FORMIDABLE TASK IN TERMS OF TIME AND MONEY. SUCH WORK HAS BECOME INCREDIBLY COSTLY, TO THE POINT WHERE ALLOY PRODUCERS AND USERS ALONE CANNOT AFFORD IT. HENCE, GOVERNMENT FUNDS SUPPORT MUCH ALLOY DEVELOPMENT EFFORT. THE TIME REQUIRED TO COMMERCIALIZE A NEW SUPERALLOY IS IN THE ORDER OF FIVE TO TEN YEARS, AND IF WE COUPLE ALL THIS WITH NATIONAL PRIORITIES FOR AIR DEFENSE AND ESSENTIAL AIR TRAVEL, I THINK WE CAN SAFELY CONCLUDE THAT THIS FIELD DOES NOT OFFER MUCH PROMISE FOR THE CONSERVATION OF CHROMIUM. (SLIDE OFF)

THE SUBSTITUTION OF NICKEL FOR ELEMENTS BESIDES CHROMIUM IN HIGH TEMPERATURE ALLOYS HAS BEEN REVIEWED IN EARLIER SESSIONS OF THIS CONFERENCE AND AT OTHER CONFERENCES.[10] THEREFORE, WE WILL NOT SPEND MUCH TIME IN THIS AREA EXCEPT TO RECORD THAT THERE APPEARS TO BE SOME PROGRESS IN REPLACING COBALT WITH NICKEL. A NEW APPROACH TO MORE EFFICIENT ALLOY UTILIZATION IS INCO'S WORK ON MECHANICAL ALLOYING BY HIGH ENERGY MILLING. THIS TECHNIQUE PERMITS THE COMPOUNDING OF ALLOYS WHICH WOULD BE DIFFICULT OR IMPOSSIBLE TO PRODUCE BY CONVENTIONAL MANUFACTURING ROUTES.[11] HERE ARE THE CHEMICAL COMPOSITIONS OF TWO NEW PRODUCTS, MADE BY MECHANICAL ALLOYING, FOR GAS TURBINE VANES AND BLADES.

SLIDE NO. 6 - NEW GAS TURBINE MATERIALS PRODUCED BY MECHANICAL ALLOYING

I THINK THE IMPORTANT FACTOR HERE IS THAT SUPERIOR PERFORMANCE CAN RESULT IN AN OVERALL CONSERVATION OF MATERIALS, NOT JUST THE ELMINIATION OF COBALT. (SLIDE OFF)

PLATING IS THE NEXT MARKET SECTOR FOR ATTENTION IN THIS REPORT. YOU KNOW THAT CHROMIUM IS USED FOR DURABLE, BRIGHT FINISHES ON COUNTLESS ITEMS, ESPECIALLY HOUSEWARES AND AUTOMOTIVE COMPONENTS. TYPICAL PLATING SYSTEMS FOR DECORATIVE SURFACES INCLUDE BRIGHT NICKEL DEPOSITS UP TO 1.5 MILS DEEP COVERED WITH 10 TO 15 MICROINCHES OF CHROMIUM, PRIMARILY FOR CORROSION RESISTANCE. SOME MACHINERY APPLICATIONS, SUCH AS HYDRAULIC PISTONS, UTILIZE THICK, HARD CHROMIUM COATINGS FOR WEAR RESISTANCE. IN ALL, THE ANNUAL U.S. CONSUMPTION OF CHROMIUM FOR PLATING OTHER METALS IS ABOUT 15,000 TONS.

AS WE THINK ABOUT CHROMIUM CONSERVATION, IT IS INTERESTING TO RECALL THAT NICKEL PLATING WAS WIDELY USED LONG BEFORE CHROME FINISHES BECAME POPULAR. IN FACT, THE PROCESS WAS PATENTED BACK IN 1840, AND BY THE TURN OF THE CENTURY NICKEL PLATING HAD BECOME A SYMBOL OF QUALITY. IT BECAME THE HABIT TO CALL ANY ARTICLE OR PROJECT OF COMMENDABLE CHARACTER "NICKEL PLATED". THUS, THE NEW YORK, CHICAGO AND ST. LOUIS RAILROAD, BECAUSE OF ITS HIGH-GRADE ENGINEERING AND STRONG FINANCIAL BACKING, GAINED THE NAME OF THE "NICKEL PLATE ROAD".[12]

IF CHROMIUM FOR PLATING WERE TO BE RESTRICTED, SUCH AN EVENT COULD NOW BE MET WITH BRIGHT NICKEL SURFACES PROTECTED

BY VARIOUS TRANSPARENT ORGANIC COATINGS. ADDITIONALLY, HARD NICKEL PLATING PROCESSES, INCLUDING THOSE FEATURING THE USE OF ABRASION RESISTING DISPERSOIDS HAVE BEEN DEVELOPED FOR THE PROTECTION OF MACHINERY PARTS.

MANY OF THE MATERIALS WE HAVE DISCUSSED ARE ALSO AVAILABLE AS CASTINGS. CONSERVATION OF CHROMIUM IN THE CAST HEAT AND CORROSION RESISTANT STAINLESS ALLOYS IS POSSIBLE THROUGH THE USE OF THE NI-RESIST* FAMILY OF CAST IRONS (ASTM A439 AND A436) WHICH RELY HEAVILY ON NICKEL, COPPER SILICON, MOLYBDENUM AND, IN SOME INSTANCES LOW PERCENTAGES OF CHROMIUM TO OBTAIN DESIRED PROPERTIES.[13]

THE AUTOMOTIVE INDUSTRY IS AVIDLY SEEKING ECONOMY IN MANUFACTURING, AND THIS HAS CREATED NEW INTEREST IN NICKEL-MOLYBDENUM CAST IRONS TO REPLACE WROUGHT STEELS IN DIESEL CRANKSHAFTS AND IN CERTAIN GEARS. THESE EVALUATIONS COULD EVENTUALLY EFFECT SOME SAVING IN CHROMIUM.

LASTLY, WE KNOW THAT SEVERAL PROMINENT PRODUCERS AND USERS OF CAST PERMANENT MAGNETS ARE CONDUCTING RESEARCH ON LOWER COBALT ALLOYS FOR USE IN ELECTRICAL MOTORS AND TELECOMMUNICATIONS.

*TRADEMARK THE INTERNATIONAL NICKEL COMPANY, INC.

TO SUMMARIZE, WE HAVE BEEN CONSIDERING TECHNOLOGICAL OPPORTUNITIES TO REPLACE CHROMIUM, COBALT AND TITANIUM WITH NICKEL, ASSUMING PLENTIFUL SUPPLIES OF NICKEL AND POSSIBLE SHORTAGES OF THE OTHER THREE METALS. OUR ANALYSIS INDICATES THAT IT WOULD BE POSSIBLE TECHNICALLY TO SUBSTITUTE NICKEL-CONTAINING MATERIALS SUCH AS MONEL FOR A SUBSTANTIAL TONNAGE OF STAINLESS STEEL. SIMILARLY, MUCH OF THE CHROMIUM IN ALLOY STEELS COULD BE REPLACED BY NICKEL, PERHAPS AUGMENTED BY INCREASED MANGANESE OR MOLYBDENUM. MOST OF THE CHROMIUM FOR PLATING OTHER METALS COULD ALSO BE SAVED THROUGH THE USE OF ALTERNATIVE NICKEL PLATING SYSTEMS.

AS TO COBALT, THE ONLY LARGE POTENTIAL FOR CONSERVATION INVOLVES SUPERALLOYS, WHERE DEVELOPMENTS ARE ALREADY TARGETED ON COBALT REDUCTIONS UTILIZING NICKEL AS THE ALTERNATE ALLOYING ELEMENT. NEW MECHANICALLY ALLOYED MATERIALS FEATURING OUTSTANDING RESISTANCE TO DETERIORATION IN VARIOUS HIGH TEMPERATURE ENVIRONMENTS ALSO OFFER OPPORTUNITIES TO CONSERVE SEVERAL CRITICAL METALS IN GAS TURBINE COMPONENTS.

SOME TITANIUM NOW EMPLOYED FOR VARIOUS AEROSPACE, PAPER MILL AND CHEMICAL PLANT APPLICATIONS COULD BE SAVED THROUGH SUBSTITUTION WITH HIGH STRENGTH STEELS CONTAINING NICKEL AND WITH HIGH NICKEL CORROSION RESISTING ALLOYS. UNFORTUNATELY, THESE ALTERNATE MATERIALS REQUIRE CHROMIUM OR COBALT.

THIS CONCLUDES MY PRESENTATION.

THANK YOU.

References

(1) Chromium in December 1980, Mineral Industry Surveys, U.S. Department of the Interior, Bureau of Mines.

(2) Fifty Years of Stainless Steel, H. Krainer, Stahl and Eisen, 82, Oct. 25, 1962, 1527-1540. British Iron and Steel Institute Translation No. 3081

(3) A History of Nickel Steels, R.B.G. Yeo and O.O. Miller, Sorby Centennial Symposium on the History of Metallurgy, AIME 1965. Gordon and Breach Science Publishers, New York. International Nickel A-408, 1966.

(4) Chromium Substitution in Stainless Steels, S. Floreen, Contract No. J0295070, U.S. Dept. of Interior, Bureau of Mines, November 1980.

(5) Low Chromium Oxidation Resistant Austenitic Stainless Steel, U.S. Patent No. 4,102,225, H. T. Michels, July 25, 1978, The International Nickel Company, Inc.

(6) Cleavage Initiation in Fe-Ni Alloys, Floreen, Met. Trans., Vol. 2, May 1971, 1403.

(7) The Effect of Nickel on the High Temperature Oxidation Characteristics of Copper-Bearing Steels, G.L. Fisher, Jnl. Iron and Steel Institute, Vol. 207, July 1969.

(8) Titanium 1980, W. W. Minkler, Journal of Metals, April 1981, 41-44.

(9) HIGH TEMPERATURE HIGH STRENGTH NICKEL BASE ALLOYS, INTERNATIONAL NICKEL A-393, 1977

(10) SUPERALLOYS 1980, J. K. TIEN, ET AL, AMERICAN SOCIETY FOR METALS, PROCEEDINGS FOURTH INTERNATIONAL SYMPOSIUM ON SUPERALLOYS, SEPT. 21-25, 1980.

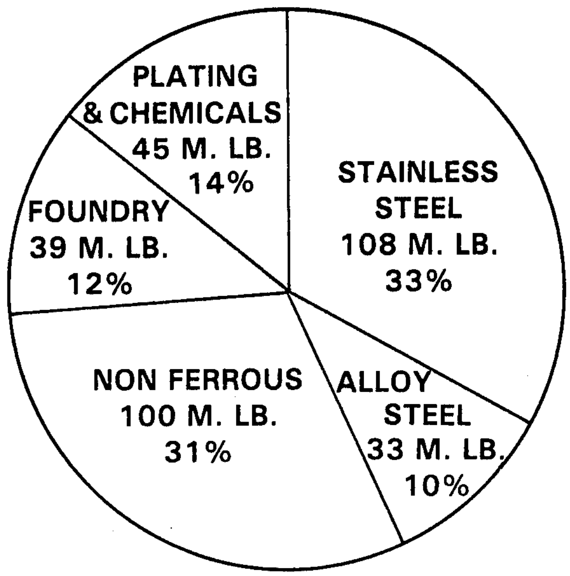
(11) HIGH TEMPERATURE OXIDE DISPERSION STRENGTHENED ALLOYS, J. H. WEBER, SCIENCE OF ADVANCED MATERIALS AND PROCESSES ENGINEERING, VOL. 25, 1980, 752-764

(12) AUTOMOTIVE INDUSTRY OF AMERICA, PRESTIGE PUBLICATIONS, INC., SOUTHFIELD, MICHIGAN, 1979, 189-193

(13) ENGINEERING PROPERTIES AND APPLICATIONS OF THE NI-RESISTS AND DUCTILE NI-RESISTS, INTERNATIONAL NICKEL A-1231, 1975

COMMERCIAL NICKEL SOURCES

U.S.A. PRIMARY NICKEL CONSUMPTION BY END-USE MARKETS



Total 1980 Shipments – 325 Million Pounds.

POSSIBLE SUBSTITUTES FOR STAINLESS STEELS TO CONSERVE CHROMIUM

Nickel Silver (55 Copper–18 Nickel–Bal. Zinc)

Monel (30 Copper–Bal. Nickel)

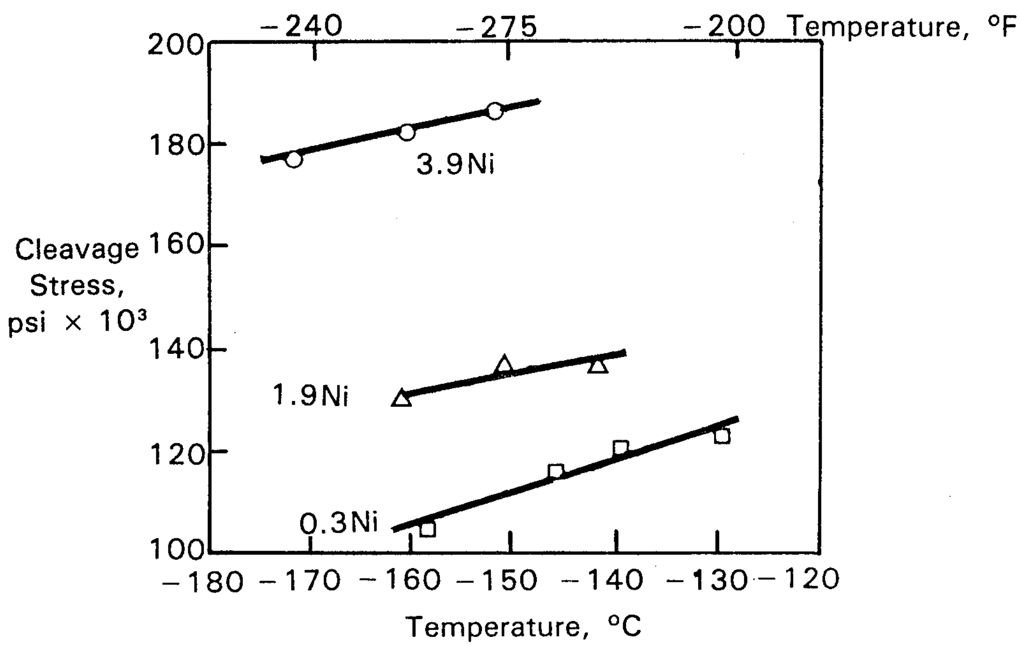
Cupronickel (90 Copper–10 Nickel)

Aluminum

Plastics

Coatings

EFFECT OF NICKEL ON THE CLEAVAGE STRENGTH OF IRON



CONSTITUENTS OF HIGH TEMPERATURE ALLOYS

Element	Occurrence – Number of Alloys
Cr	91
Al	79
Ti	72
Mo	63
B	60
Co	55
Zr	45
W	37
Cb	29
Ta	17

NEW GAS TURBINE MATERIALS PRODUCED BY MECHANICAL ALLOYING

	MA754	MA6000E
Ni	Bal	Bal
Cr	20.0	15.0
Mo	—	2.0
Al	0.3	4.5
Ti	0.5	2.5
Ta	—	2.0
W	—	4.0
Zr	—	.15
B	—	.01
C	.05	.05
Y_2O_3	0.6	1.1

TUNGSTEN - A NEWLY NONCRITICAL METAL

C. C. Tungsten
AMAX Tungsten

TUNGSTEN - A NEWLY NON-CRITICAL METAL

C. C. Clark*

Tungsten has had a long history as a critical material; one intimately related to military necessities such as cutting tools, armor piercing projectiles and high-temperature alloys. In view of this historical usage association and a common misconception in this country that most of our tungsten comes from Eastern Bloc countries, it may come as a surprise to some of you to find that tungsten is included as a "safe" element to be used as a replacement of critical elements. I would like, therefore, to take a few minutes to bring you up-to-date on the current and future tungsten supply situation.

TUNGSTEN SUPPLY

Any analysis of the tungsten industry must consider the impact of the U.S. stockpile on prices, and new mine development. In 1950-51 during the Korean War the General Services Administration increased its tungsten stockpile goal to 146 million pounds[1], Figure 1. Prices became so attractive that by 1955 more than 700 tungsten mines were operating in the United States. They produced almost 16 million pounds. Actual stockpile purchases far exceeded the 146 million pound objective and reached 210 million pounds before the program ended in 1957. To place that in perspective, consider that the 210 million pounds could have supplied the whole Western World for six years at the 1957 level of consumption.

The stockpile objective was revised downward several times and by 1958 had reached 50 million pounds leaving a 160 million pound excess which could have supplied all of the U.S. needs between 1959 and 1971. As a consequence the number of U.S. producers fell to two and by 1962 the price had fallen to 50¢/lb., Figure 2, when the GSA began its tungsten disposal program.

The ups and downs of the disposal program had its influence on prices. The impact of 16.2 and 28.7 million pound releases in 1969 and 1970, respectively, which drove prices from $5.05/lb. in 1970 to about $2.00/lb. in 1972, have been well documented[1, 2]. Currently, the stockpile contains a little over 90 million pounds which is only about 33 million pounds over the 59.1 million pound objective. We do not feel that this is a fail-safe situation but

*Manager, Market Development, AMAX Tungsten, P. O. Box 1568, Ann Arbor, MI 48106 (313-761-2300). Presented at the DOC-ASM Workshop on Conservation and Substitution for Critical Materials, Vanderbilt University, Nashville, TN - June 15-17, 1981.

it is a manageable level if the sealed bid-maximum quantity sales system now in effect is diligently carried out. Releases from the GSA stockpile have been 4 to 6 million pounds per year for the last several years.

Now the industry is beginning to feel confident and is making long range plans with some assurance. New mines have been brought into production or expanded since 1975, Table I, and more are scheduled in the near future, Table II. The largest of these is AMAX's huge MacTung deposit near the MacMillan Pass on the Yukon-Northwest Territories border. This scheelite deposit is estimated to contain 63 million tons of ore averaging 0.95% WO_3. This corresponds to 431,000 metric tons of tungsten. To place that in perspective with other deposits, consider the fact that the Peoples' Republic of China is estimated[3] to have "known and probable tungsten reserves" of 952,600 metric tons, Table III. Thus, this one deposit contains the equivalent of 40% of the estimated Chinese tungsten deposits. It should be noted, however, that the MacTung deposit was discovered in 1962 but its development could not be justified because of the large quantity of excess tungsten overhanging the marketplace in the GSA stockpile. The decision to proceed with the development of MacTung is expected sometime in 1981. Its initial production at the rate of about 7 million pounds per year will substantially increase the supply of tungsten from stable areas, Figure 3.

Our estimate of the tungsten supply-demand for the Western World is shown in Figure 4. What is of perhaps even greater importance is that North America is expected to become self-sufficient in tungsten before the end of this decade, Figure 5.

There is a misconception in this country that China and North Korea are large suppliers of tungsten to the Western World. It is not possible to get accurate figures on this because statistics are sparse and the trade flow is complex. Our observation is that these countries have not been able to satisfy Eastern Bloc needs in recent years and that there has been a net flow from the West to the East for most of the past ten years.

The impact of the GSA tungsten stockpile on the tungsten industry is not an isolated case. Other metals, especially those critical materials which we are talking about replacing, were released in quantity during the 1970's. In many instances shortages soon developed[4] because the mining industry simply could not justify bringing new mines into operation as long as the GSA was acting as a "major mine". Another way of saying this is that artifical markets which exist when normal commercial materials' economics are disregarded make it difficult, if not impossible, for an industry to develop in an orderly fashion.

Now this country's metallurgical and scientific community is embarking on a program to implement the recently enacted National

Materials Minerals, and Research and Development Act of 1980 (PL96-479). We will undoubtedly become engaged in federally funded programs and I hope that established materials economics, normal commercial business practices, and just plain common sense will not be ignored. The tungsten industry has felt the effects when these factors were ignored and I for one am concerned about the wisdom of embarking on an R & D program such as we are discussing at this meeting.

TUNGSTEN APPLICATIONS

Rather than speculate on ways that tungsten or tungsten containing alloys might substitute for the critical elements and their alloys, I am going to touch upon some of the benefits tungsten imparts to various alloy systems. Some examples will be discussed. I think that this is the way that I can be most helpful to you in your efforts to consider viable alternate alloys with lower critical element content.

CEMENTED CARBIDES

Approximately 65% of the tungsten consumed in the U.S. is used in cemented carbides. Tungsten carbide has formed the backbone of the carbide industry for many years because it provides the combination of hardness, transverse rupture strength and toughness necessary for many tough wear applications in the oil drilling, mining and many industrial wear applications. These applications utilize grades which contain 8-30% cobalt which some of you may consider a logical target for substitution, despite the fact that less than 10% of the cobalt is used in cemented carbides. Much effort has been devoted to this over the years but so far no binder has been found which does not impair properties. Furthermore, the high cobalt and tantalum values have spurred development of processes to recycle carbides. Currently, the industry is recycling a high proportion of the scrap carbides so that little cobalt is actually being consumed. More about that later.

Let's not forget that productivity is an all important consideration in a business/political climate which leads to materials shortages. In fact, as we all know the U.S. seriously lags other countries in productivity even in today's sluggish economy. The use of coated tungsten carbides has grown rapidly in the last few years and has significantly improved machine productivity by increasing machining speeds[5], Figure 6. The use of coated tools could reach 80% in several years especially as old slower machines are replaced.

These coatings consist of 5-15μ thick layers of alumina, TiC, TiN, or other very hard but brittle ceramic type materials. To be sure, they do not permit operation in the speed ranges of the

cements and ceramics but they significantly extend the speed range of uncoated WC. Most machine tools operating today cannot achieve speeds and the rigidity required to take advantage of the cermets.

Since coatings are brittle, care must be taken to be sure that the substrate provides the required properties[6]. High deformation resistance is necessary to prevent flaking of the coating and to maintain the original cutting edge geometry. At the same time, high toughness is necessary to maintain resistance to crack initiation and propagation. Cemented tungsten carbides can be tailored to provide optimum substrate properties often through addition of other carbides.

Since cemented tungsten carbide is so essential to high productivity, it is important that the critical elements such as cobalt and tantalum used in concert with the WC be recovered. Several processes have been developed, Figure 7, which are capable of recycling carbide compacts. In some, such as the zinc process, these elements remain in situ and the product of the process is a ready-to-press powder which I understand is suitable for most cemented carbide applications. The zinc process is reported to be very energy efficient utilizing only 3.6 kw hr./kg. The process is very efficient as metallic recoveries are on the order of 99.9%.

Process efficiency is only one side of any recycling effort. Currently, recycled material represents about 25% of the cemented carbide produced today[7]. This percentage is expected to increase in the future but the actual volume recycled will depend upon prices and scrap availability. Since this meeting is concerned with material shortages, I have talked with several persons who are knowledgeable about the carbide scrap industry to get an idea of how much could be recycled in the event of a critical shortage of cobalt or tantalum and how much is being recycled today. These conversations are summarized in Table 4. A much higher percentage of the tungsten carbide consumption is available for recycling than the estimated 25% being recycled today. This combined with the high efficiency of the recycling processes makes it hard to justify any R & D effort to substitute for cobalt in carbides which are so crucial to high productivity.

HARDFACING MATERIALS

Tungsten has been used in cobalt base hard facing alloys since Elwood Haynes developed several in the early 1900's for valve overlays and other wear parts in his automobiles. The combination of excellent wear properties and unusually low coefficient of friction make one alloy, widely known as alloy No. 6, unique for many critical applications. A number of nickel and iron base hardfacing alloys are on the market which rely upon either WC or

W_2C particles to provide high wear resistance. These could be substituted for the cobalt base alloys. Tungsten carbide is ideal for this type of application because it reforms after passing through the electric arc.

Often it is not necessary to significantly alter a material to eliminate a critical element. One example is a change made by a diesel engine manufacturer in a valve seat inert, which had been cast in Eatonite for years[8]. Elimination of the 10% cobalt had little significant effect on its properties, Table 5. Old files were checked to find out why cobalt had been added in the first place. It turned out that the alloy was developed as a hard facing material and the cobalt was added to stabilize the arc. It just wasn't needed in the casting.

HIGH SPEED STEELS

Ever since the development of an 8% tungsten tool steel in 1868, tungsten has been an important alloying addition in tool and high speed steels. Changing mineral economics have resulted in substitution for tungsten by molybdenum, vanadium and chromium. For those applications which require high hardness at high temperatures, commonly referred to as red hardness, it was often necessary to add cobalt along with the tungsten substitutes. Now the trend has reversed itself and it is cost effective to substitute tungsten for the cobalt.

W. T. Haswell's presentation earlier in these meetings on the development of CPM Rex 20 and 25 is an example of how tungsten-molybdenum grades with higher tungsten equivalents can be substituted for the cobalt containing grades. The techniques used in developing these alloys can be utilized to develop other cobalt-free grades if the market warrants.

SUPERALLOYS

Tungsten's role as a carbide former and strengthener in cobalt base superalloys is well known. Because of the ready availability of molybdenum, tungsten's potent contribution to nickel base alloys was largely overlooked in this country until the Martin Metals series and the hot corrosion resistant alloys were developed in the]960's. Russian alloys have always utilized more tungsten.

Actually tungsten contributes many beneficial characteristics to nickel base alloys:

- Potent solid solution strengthener, especially at highest temperatures and longest times.

- Solid solution strengthens γ'.

- Carbide stabilizer - MC type.
- Raises melting point.
- Reduces thermal expansion.
- Reduces diffusivity of Ti and Cr at high temperatures.
- Probably raises γ' solvus temperature.
- Retards transformation of γ' to η.

Tungsten's most potent contribution is as a solid solution strengthener and carbide stabilizer. In fact, it contributes to long time microstructural and dimensional stability in many different ways and its effect seems to persist to the highest temperatures. An example is the Japanese[9] development of an alloy for use in high temperature gas cooled reactors. Its long time rupture strengths are compared in Figure 8 with those of cobalt containing alloy 617 which is receiving a lot of attention in this country for similar applications. These data support the position that tungsten is a potent strengthener at high temperatures and long times; even more so than molybdenum on an atomic percent basis. However, the density of tungsten is appreciably higher.

Alloys such as the Japanese HTGR alloy can help this nation utilize its fuel resources more efficiently. Boilers, reactors, etc., are designed for very long time service and require materials which will maintain their properties for the life of the unit. One example is IN-102 with 3% each of tungsten, molybdenum and columbium which was developed specifically for superheater tubing in fossil-fired power plants operating with 1200F steam. Perhaps someone should look at a rebalanced columbium-free version of this alloy for possible application in high temperature steam plants. The alloy not only provides much higher strength than 18-8 type stainless steels so that thinner wall tubes can be used but it has only 15% chromium. Use of such an alloy could result in substantial chromium savings. Test lengths have been operating satisfactorily in a Public Service boiler for well over 10 years.

HIGH TEMPERATURE STEELS

Tungsten imparts the same beneficial characteristics to elevated temperature steels that molybdenum does on roughly an equivalent percent basis:

- Tungsten imparts resistance to hydrogen attack.
- Tungsten imparts resistance to temper embrittlement.
- Tungsten increases elevated temperature strength.
- Tungsten stabilizes carbides.

In fact, it may be a sufficiently potent carbide stabilizer that it might prevent graphitization. This is one application wherein tungsten might substitute directly for chromium in the low Cr-Mo steels.

There are data which show that, as in superalloys, tungsten is most effective as a strengthener at long times and at the highest temperatures. One important example of this is HT-9, a Super 12% chromium stainless steel, which has been widely used in Europe and is receiving consideration in this country for various elevated temperature applications. Sandvik[10] has found a consistent 10-15% higher rupture strength in HT9 with 0.5% tungsten than the identical, but tungsten free, HT91. The advantages of HT9 are:

- Excellent operating experience in Europe for over 20 years.
- Significantly improved strength over standard 9Cr-1Mo.
- Data base available for establishment of ASME Codes.
- Good resistance to fireside corrosion.
- Lower chromium content (11.5%) than austenitic stainless steel.
- No other "critical" material content.

Very approximate maximum allowable stresses, based on Section VIII, Division 1 of the ASME Boiler and Pressure Vessel Code are compared in Figure 9 with those of commonly used boiler tube materials and the modified 9Cr-1Mo[11] steel under development by Oak Ridge National Laboratory and Combustion Engineering. HT9 is not quite so strong as the modified 9Cr-1Mo, but it has given good service in superheater tubes in Europe where it has demonstrated better resistance to fireside corrosion than Type 304 stainless steel. Frankly, it makes sense to utilize HT9 in this country right now regardless of the chromium supply situation.

SUMMARY

Tungsten has been neglected as an alloying element in many systems because of its volatile commercial history and belief that most of our supply comes from Asia. We in AMAX believe that tungsten will find many uses and will be a useful substitute for many of the critical elements. Some of the suggestions made in this presentation are being included in on-going programs in our Ann Arbor Research Laboratory. Hopefully, some of these will come to fruition in time to help better define this country's critical material alternatives and to plan a practical substitution program.

In our opinion, the Government can help most by providing a business climate wherein natural market forces can correct supply aberrations such as occurred in the cobalt industry and new sources of supply can be developed. After all, as many a good geologist has said, "Show me a shortage and I will soon give you an over-supply".

REFERENCES

1. K. J. A. Kundig, The Tungsten Market - From Chaos to Stability, J. Metals, May, 1981.

2. C. C. Clark and J. B. Sutliff, Current and Future Tungsten Supplies, Presented at Second Charlottesville Conference on High Energy KE Penetrator Materials, Charlottesville, VA, October 14-17, 1980.

3. Bundesanstalt fur Geowissenschaften und Rohstoffe, Hannover, Fed. Rep. of Germany, Deutsches Institut fur Wirtschaftsforschung, Berlin, September 1977.

4. R. E. Schwer, Critical Materials and the Need for a Materials Policy, Presented at ASME Gas Turbine Conference, New Orleans, LA, March 10, 1980.

5. H. S. Kalish, An Update - New Developments in Cutting Tools, International Conference on Cutting Tool Materials for the 80's, Purdue University, Lafayette, IN, June 1980.

6. J. G. Baldoni, State of the Art in Coated Carbides, The Carbide and Tool Journal, November-December 1980.

7. B. F. Kieffer and E. F. Baroch, Recycle of Tungsten Carbide and Mill Scrap, Presented at AIME Annual Meeting, Chicago IL, February 23-25, 1981.

8. C. C. Clark, Practical Substitutions for Cobalt Base Superalloys, ASM Westec Conference, March 19, 1979.

9. Report on Investigation of Direct Iron Making by High Temperature Reducing Gas, Association for Atomic Energy Iron Making, Ministry for International Trade and Industry, Japan, March 1981.

10. L. Egnell and N. G. Persson, On The Creep Properties of Sandvik HT7 and HT9, Presented at International Conference on Ferritic Steels for Fast Reactor Steam Generators, London, 1977.

11. M. K. Booker, V. K. Sikka and B. L. P. Booker, Comparison of Several High-Chromium Ferritic Steels, ORNL/TM-7500, October 1980.

TABLE 1
TUNGSTEN MINE EXPANSIONS AND OPENINGS BETWEEN 1975 AND 1980
(Millions Pounds Tungsten/Year)

COMPANY	MINE	LOCATION	DATE EXPANDED OR OPENED(*)	ESTIMATED PRODUCTION 1975	1980	INCREASE 1975-1980
Canada Tungsten	Cantung	Canada	1976-79	2.6	7.3	4.7
King Is. Scheelite	King Is.	Australia	1975-77	2.7	4.5	1.8
Queensland Wolfram	Mt. Carbine	Australia	1977	0.2	1.6	1.4
Misc. Thailand		Thailand	1978	1.5	3.9	2.4
Misc. Bolivia		Bolivia	1975	0.2	1.5	1.3
Metallgesellschaft	Mittersill	Austria	1976*	—	2.7	2.7
Pacific Copper	Glen Innes	Australia	1979*	—	1.3	1.3
Union Carbide	Emerson	Nev. U.S.	1978*	—	1.0	1.0
Union Carbide	Boca De Laga	Brazil	1977*	—	1.0	1.0
Teledyne Wah Chang	Strawberry	Calif. U.S.	1978*	—	0.9	0.9
			Total	7.2	25.7	18.5
			Western World Total	41.4	60.6	19.2

9/80

TABLE 2
TUNGSTEN MINE EXPANSIONS AND OPENINGS BETWEEN 1980 AND 1985
(Millions Pounds Tungsten/Year)

COMPANY	MINE	LOCATION	DATE EXPANDED OR OPENED	ESTIMATED PRODUCTION 1980	1985	INCREASE 1980-1985
AMAX	Mactung	Canada	Open 1984	—	7.1*	7.1
AMAX	Hemerdon**	U.K	Open 1985	—	4.0	4.0
Brunswick Tin	Mount Pleasant	Canada	Open 1982	—	3.2	3.2
General Electric	Springer	Nev. U.S.	Open 1982	—	1.6	1.6
Union Carbide	Emerson	Nev. U.S.	1981	1.0	2.0	1.0
			Total	1.0	17.9	16.9
			Total Western World	60.6	76.6	16.0

*Initial Capacity
**Preliminary Feasibility Estimate

TABLE 3
WORLD TUNGSTEN RESERVES[3]
(1000 metric tons)

	KNOWN & PROBABLE RESERVES	POTENTIAL RESERVES
PEOPLE'S REPUBLIC OF CHINA	952.6	1,814.4
CANADA	245.0*	317.5
SOVIET UNION	215.0	261.3
NORTH KOREA	113.4	136.1
U.S.	108.9	326.6
AUSTRALIA	65.0	75.0
SOUTH KOREA	45.4	79.8
BRAZIL	42.0	19.3
BOLIVIA	40.0	83.9
OTHER COUNTRIES	215.2	282.5
TOTAL	2,032.5	3,396.4

*AMAX REVISION 1981 - 457.0

TABLE 4
ESTIMATED CARBIDE RECYCLING BY CEMENTED CARBIDE APPLICATION

APPLICATION	THEORETICAL MAXIMUM - %	PROBABLE PRACTICAL LIMIT - %	CURRENT - %
CUTTING TOOL INSERTS	95	60	40
BRAZED TOLLS	75	40	15
OIL DRILLING	90	85	80
COAL MINING	65	50	15
MINING	85	85	65
WEAR PARTS	90	85	80

TABLE 5
PROPERTIES OF COBALT-FREE EATONITE DIESEL ENGINE VALVE SEAT INSERT

COMPOSITION	EATONITE	Co-FREE EATONITE
C	2.3	2.3
Cr	29	29
W	15	15
Fe	8	8
Co	10	—
Ni	Bal	Bal
Tensile Strength	50,000 PSI	53,000 PSI
Elongation	0.5%	1.3%
Stress for 100 Hr Rupture at 1400 F	30,000 PSI	26,000 PSI
Hot Hardness		
RT	46 HRC	42 HRC
800 F	42	37
1000 F	34	37
1200 F	33	27
Coeff. of Expansion: RT - 1400 F	7.9×10^{-6}/F	7.4×10^{-6}/F
Adhesive Wear at 800 F	-2.2 MG	-1.4 MG
		-3.0 MG

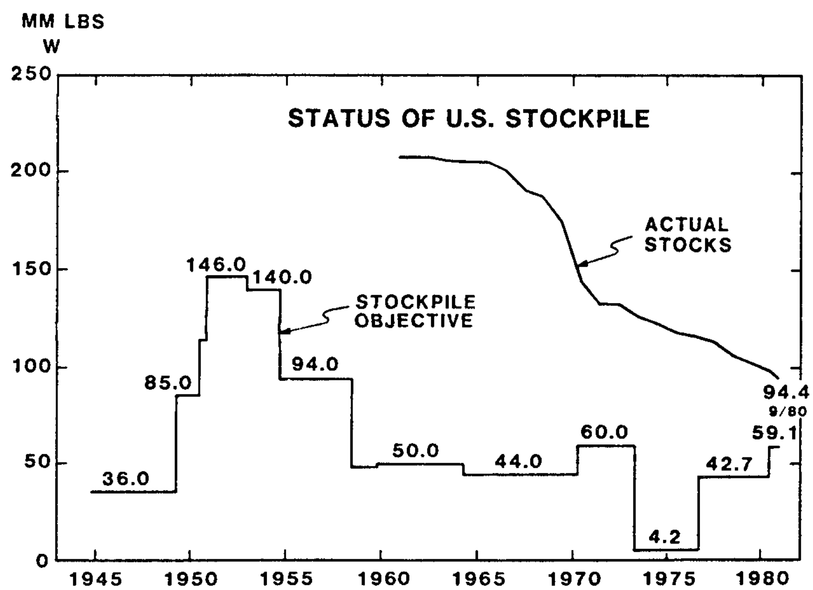


FIGURE 1.

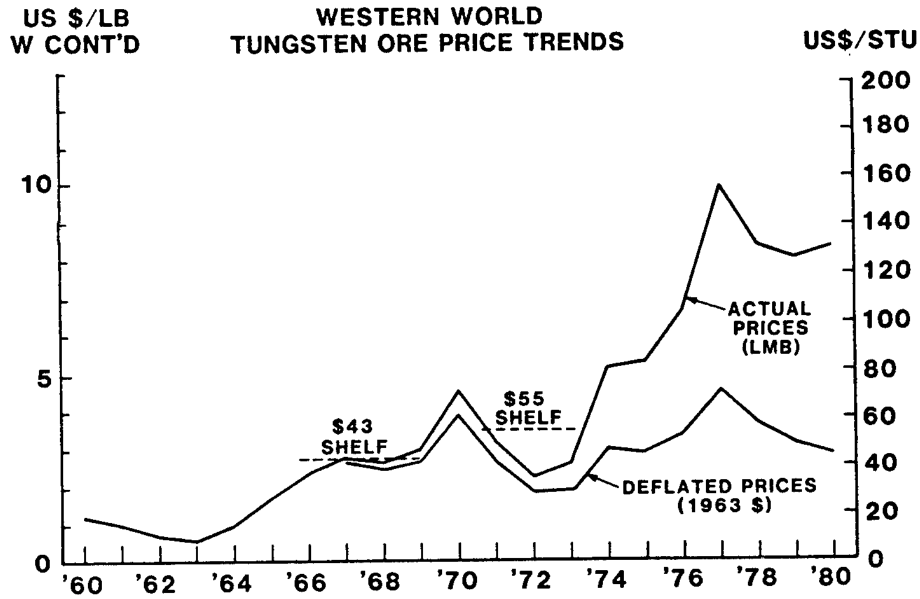


FIGURE 2.

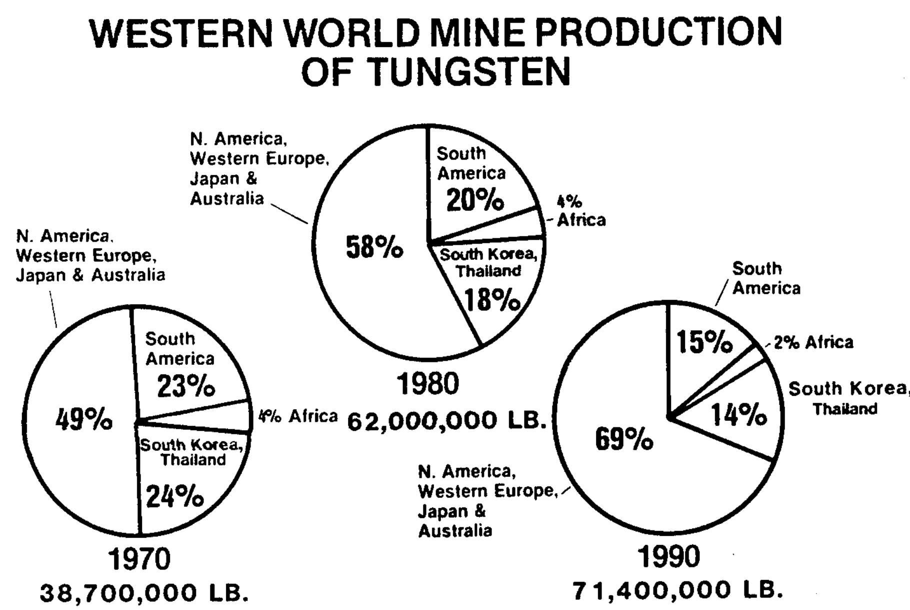


FIGURE 3.

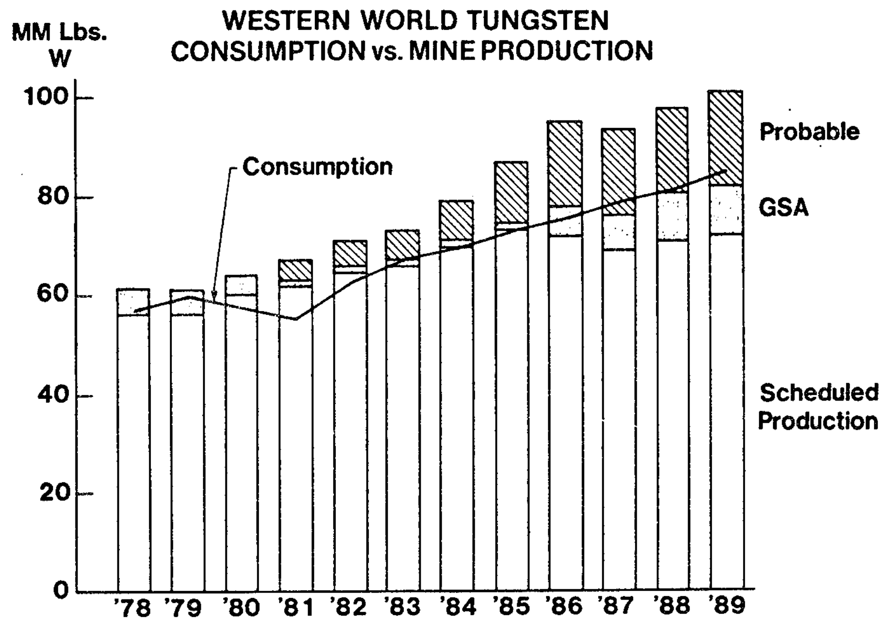


FIGURE 4

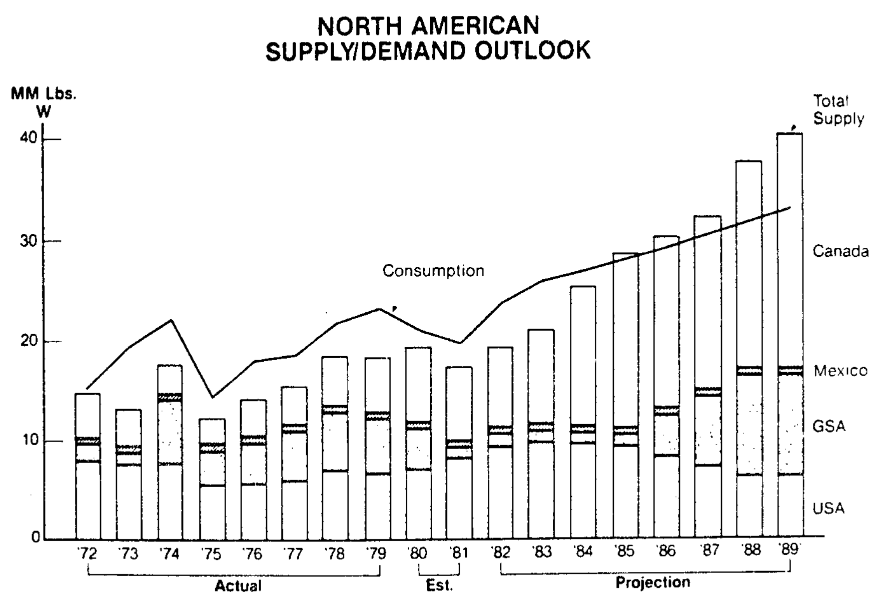


FIGURE 5.

USEAGE OF VARIOUS CUTTING TOOLS AND THEIR SPEED RANGES

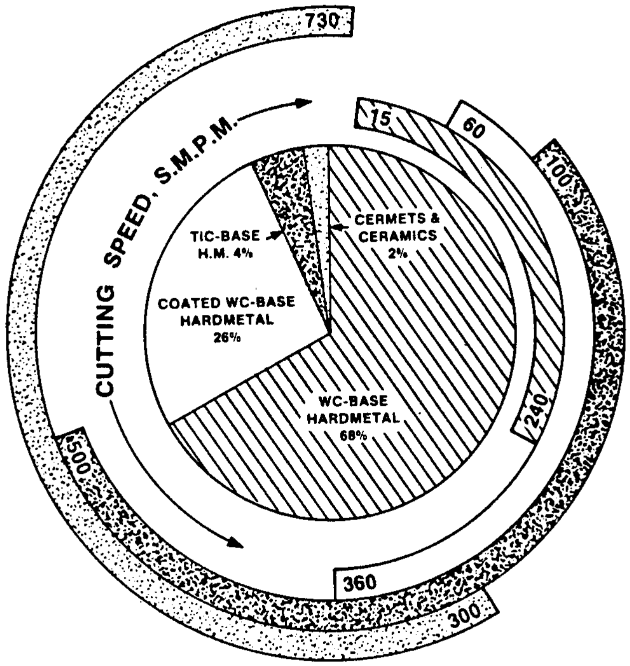


FIGURE 6.

CEMENTED CARBIDE SCRAP

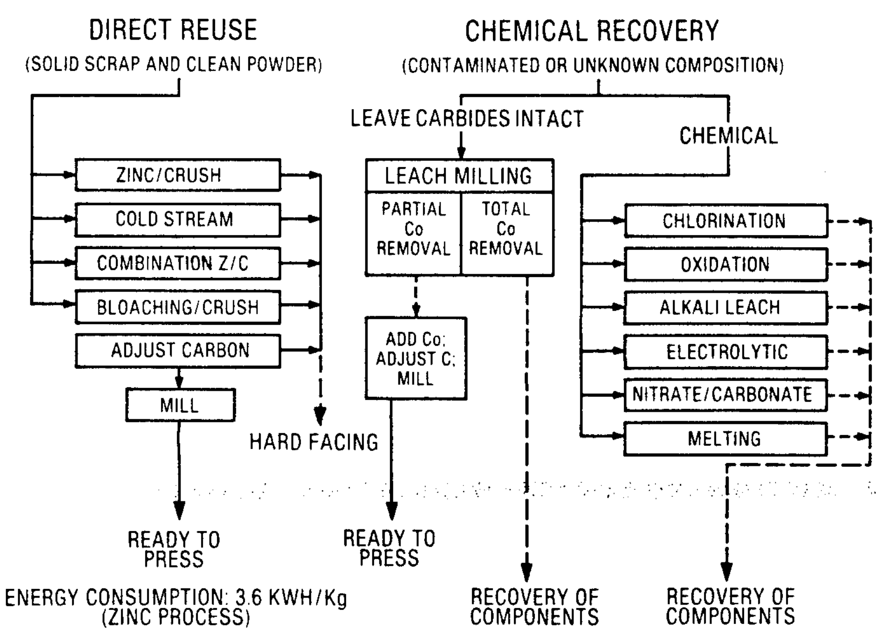


FIGURE 7.

RUPTURE STRENGTH OF JAPANESE HTGR ALLOY COMPARED WITH ALLOY 617

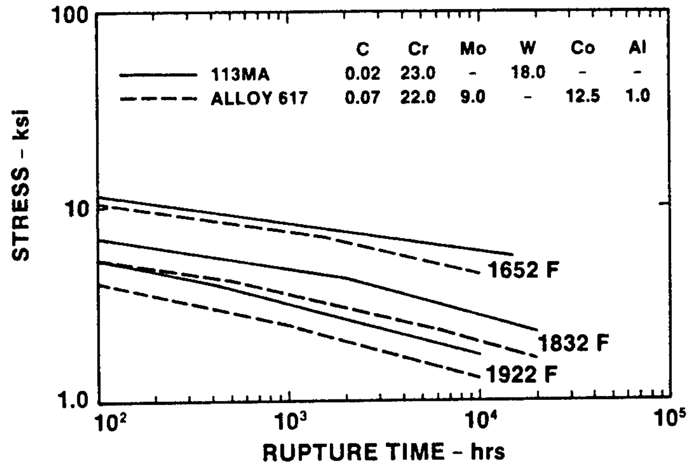


FIGURE 8.

MAXIMUM ALLOWABLE STRESSES FOR SEVERAL FERRITIC STEELS BASED ON ASME CODE SECTION VIII DIV 1.

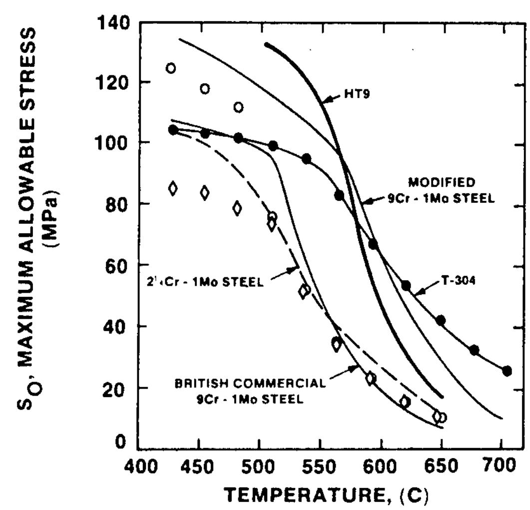


FIGURE 9.

NEW APPLICATIONS OF VANADIUM IN STEELS TO SAVE COST, ALLOYING AND ENERGY

P. L. Mangonon

Foote Mineral Co.

FASRAD 81-4

New Applications Of Vanadium In Steels To Save Cost, Alloying And Energy*

by

P. L. Mangonon
Manager, Steel R&D
Foote Mineral Co.
Route 100
Exton, PA. 19341

Abstract

New applications of vanadium in heat-treated and as-forged steels are indicated where considerable savings in costs, alloying and energy might be realized. In the heat-treated steels, the substitution of one-part vanadium for two-parts of molybdenum was shown to be effective both in the laboratory and in commercial parts. In the laboratory, it was also shown that a favorable interaction of Mo and V exist when both are present in steel which offers economic advantages. Applications of as-forged automotive components made with vanadium microalloyed steels offer cost and energy savings.

* Presented at the Workshop on Conservation and Substitution Technology for Critical Materials June 15-17, 1981, Vanderbilt University, Nashville, Tennessee.

Introduction

During the seventies, the vulnerability of the United States with regards to critical materials and energy was exposed. This has led to the establishment of the National Minerals and Materials of 1980 Policy. In addition, as a result of the shortages, conservation and substitution of materials and energy were very common. This paper points out the new applications of vanadium to save materials, energy and cost.

Applications of Vanadium in Constructional Alloy Steels

Constructional alloy steels are principally used for structural members of moving vehicles, i.e. automobiles, aircraft and off-highway vehicles, as well as oil-drilling and farm equipments requiring quenching and tempering. In 1980, an examination of the SAE alloy steel compositions reveals that only two standard steel grades, 6118 and 6150, contain vanadium out of the 86 listed.(1) In this same handbook are listed 96 formerly standard SAE alloy steels, 11 of which contain vanadium. It is obvious that the application of vanadium in alloy steels has declined in recent years.

However, the history of alloy steel usage in this country shows that vanadium steels were prominently used in the automotive industry.(2) Figure 1 shows that the usage of vanadium peaked in 1920 and has been in constant decline since. The principal replacement for vanadium in alloy steels was molybdenum and the principal reasons for the replacement were availability and price(2) - the same subjects that this workshop is concerned

about. In the early 1900's Peru was a substantial supplier of vanadium.(3) The vanadium mine was located in a remote area in western Peru and its development was indeed costly. When the site was first developed, the nearest railroad was 24.5 tortuous miles, not intended for vehicles carrying the ore. To haul the ore, llamas were used until 1920 when a narrow gauge railroad was laid. The ores were concentrated to essentially vanadium pentoxide and then shipped to Bridgeville, Pennsylvania where they were converted to ferrovanadium as the alloying additive to steel.

Compared to molybdenum which is in abundant supply in this country, vanadium has until recently been traditionally higher in price than molybdenum. As late as 1973, vanadium cost twice as much as molybdenum. It is not altogether surprising that molybdenum vis-a-vis vanadium established itself in alloy steels because of economics and availability. Figure 2 depicts the takeover of molybdenum from vanadium in alloy steels to the extent that in 1980, 56 out of 86 listed SAE standard alloy steels contain molybdenum - all but four contain less than 0.30% Mo. Inspite of this seemingly small percent addition, molybdenum consumption in alloy steels has been about 46-50% of its total consumption - the major portion of its market.

The second half of the seventies showed a great demand for molybdenum, putting pressures on supply and depleting inventories. The result was the tremendous surge in molybdenum price such that in 1979 this exceeded the price of vanadium for the

first time. There was in fact a three-tier pricing - the official domestic price, the export price and the "free market" price which were rumored to go as high as $30.00 a pound. Steel producers were forced to pass on to customers molybdenum sur-charges to compensate for their costs.

The situation just described provided an opportunity for vanadium to be applied again in alloy steels. Unfortunately, there was insufficient information in the literature about vanadium usage in heat treated steels. The information available was confused and conflicting and was done without regards to possible alloy interactions.

In an effort to determine the real effects of vanadium in alloy steels, the basic hardenabilities of medium-carbon standard alloy grades modified with vanadium were studied. The results [4,5,6] substantiated earlier results on mild steel[7] that vanadium is twice as potent as molybdenum in increasing hardenability. Translated in another way, it was demonstrated that one weight percent of vanadium can be substituted for two weight percent of molybdenum to attain the same hardenability. In these studies, 0.30% molybdenum can be replaced by 0.15% vanadium with the standard modification in heat-treatment[4,5] or with 0.10% V and 0.10% Mo using the normal specified SAE[1] austenitizing temperature based on carbon content. These results were obtained in alloy steels containing 0.15-0.40%C which correspond to what most of the alloy steel grades contain.

A significant finding of these studies is the apparent

beneficial synergistic mutual interaction effect of molybdenum and vanadium when both are present together in the alloy. For example, the substitution of 0.10% V and 0.10% Mo for the 0.30% Mo standard composition yielded an ideal critical diameter (hardenability) in excess of that exhibited by the standard. In analyzing this situation,[6] the addition of the individual effects of molybdenum and vanadium did not sum up to the change in hardenability when both are present together. However, when analyzed statistically[6] the results show that the individual effects were much higher than those obtained experimentally and they added up to the total experimental effect of Mo and V together. This apparent discrepancy can be rationalized with the suggestion that when both are present, each of the element exerted mutually beneficial interaction effect by raising the other element's individual hardenability factor.

Some practical suggestions are being made regarding this interaction effect. It is possible for example to take advantage of the molybdenum content in scrap to yield acceptable residual molybdenum contents in steel up to 0.06% and alloy this with 0.10-0.15%V to yield the same results as the 0.30% Mo grade. It is also being suggested that the mutual interaction effect induced by vanadium is in fact equivalent to a 1:3 vanadium-for-molybdenum. Both suggestions offer tremendous material and cost savings.

Independent of the studies cited so far, Republic Steel had embarked on a similar program earlier that led to the very recent

commercialization of a Ni-Cr-V steel which is being used in an automotive part.[8] The results of this work support the laboratory results cited above and while specifically not mentioned, the resultant Ni-Cr-V steel developed is a modified 4320 with molybdenum completely substituted by vanadium in the 1:2 proportion mentioned earlier. In addition, the properties and performance of this steel approached those of higher nickel grades which can lead to a substantial cost effective substitute for these standard higher nickel alloy steels. The most significant addition of this study is the demonstration that structural components made from vanadium modified grades can be carburized and give performance as good or better than higher alloy grades.

Commercialization of this alloy was made possible by much earlier work on substitution by Republic Steel and its customer. The molybdenum supply-demand in the late seventies boosted this option to be taken from the shelf. The compositions of the laboratory heats examined are shown in Table I and Figure 3 shows the hardenability of this Ni-Cr-V steel relative to some of the steels listed in Table I. Carburizing of the steels was examined using the three cycles shown in Table II. The properties of all steels examined were generally better using cycle C and it is significant that the performance of the newly developed Ni-Cr-V steel was attained without much difference or special modification from those used for the other steels.

The hardenabilities of samples from commercial Ni-Cr-V steel heats compare very favorably with the published 4620-H and 4815-H bands shown in Figures 4 and 5, respectively. The hardenability

band of the Ni-Cr-V lies generally on the high side of the 4620-H which is the steel it was intended to replace and within the broader 4815-H band which has the higher 3.5% nickel. The average composition of the commercial heats are shown in Table III together with those of 4620 and 33L10 whose properties were compared with the newly developed Ni-Cr-V steel. The carburized properties are shown in Tables IV, V and VI and demonstrate the superiority of the Ni-Cr-V over the 4620 alloy.

Applications of Vanadium in As-Forged Automotive Parts

Many automotive components such as crankshafts, connecting rods and suspension components are produced from hot-forged bars which are commonly heat-treated to obtain the necessary properties. Typically, the steels used are medium carbon-manganese steels. Recently, it was discovered that micro-alloying additions of vanadium or columbium to these grades[10,11] enable the steel to attain the desired properties in the as-forged condition. The elimination of the heat-treating provides a significant cost saving as well as conserving energy.

In this country, applications of as-forged components cited above has not caught on as much as in Japan and Europe because the substitution of quenched and tempered martensite structures by pearlitic malleable pearlitic nodular cast irons was underway.[2] The reason for the difference in approach in the U.S. and in other countries is not entirely clear. Suffice it to say, that as-forged connecting rods, crankshafts and suspension components are commercially made in the as-forged condition.

In both Japan and Europe, the predominant micro-alloying addition for as-forged applications is vanadium. Initial development studies between Honda Motors and Daido Steel(12) in Japan indicate the importance of the as-forged hardness. The dependence of this as-forged hardness to composition was obtained by regression analysis and was shown to be

$$H_{eq} = 4.70 + 32.5(\%C) + 1.04(\%Si) + 4.14(\%Mn) \\ 1.54(\%Cr)\ 66.6(\%V) + 10.8(\%Nb) + \\ 183(\%N) \quad (1)$$

where H_{eq} is the equivalent hardness in R_c based on the specified forging conditions.(12) The regression equation was found to have a multiple correlation coefficient of R=0.983. Carbon and vanadium were considered the elements contributing significantly to the hardness. Based on this, a recommended range of composition of carbon and vanadium is shown shaded in Figure 6. The final composition of the steel selected depends on the properties but the vanadium content is limited to less than 0.2% for economy.

The hardness of the resultant component depends also on the soaking temperature before forging as well as on the cooling rate and mass of the component after forging. Thus, based on the same H_{eq}, the resultant component hardness can vary as shown in Figure 7. Higher soaking temperatures allow the vanadium to be dissolved in austenite and possibly allow the austenite grains to coarsen. Vanadium in solution and the enlarged austenite grains enhances the hardenability of the steel. Vanadium in solution in austenite lowers also the transformation point to

induce finer ferrite-pearlite structures on transformation. In addition, the vanadium in solution in austenite will be the source of further strengthening when the vanadium precipitates as fine particles in ferrite. The faster the cooling rate and lesser the mass of the component after forging, the harder will be the resultant hardness. In contrast, at lower soaking temperatures when vanadium is left undissolved in austenite, the desired strengthening effect of vanadium cannot be well demonstrated.

A comparison of tensile properties of as-forged vanadium micro-alloyed steels with those of the conventional quenched and tempered (Q+T) free-machining steels is shown in Table VII. The compositions, forging, and Q+T conditions of the steels are also given. The properties are seen to be very comparable.

Examples of parts made from the microalloyed steels are shown in Figure 8. Machinability and fatigue properties of the components are as good or better than the conventional Q+T steels. In addition, the uniformity in properties (hardness) across the sections of the parts is much better than the Q+T steel.

The microstructures of the as-forged components show typically pro-eutectoid ferrite outlining the previous austenite grain boundaries with pearlite in the interior. Consequently, in comparison to the Q+T structure which do not show this outline, the ductility and impact properties are inferior to Q+T. However, these deficiencies do not seem to be critical since the controlling property appears to be fatigue.[2,13,14] A comparison of fatigue properties of crankshafts[13] made with a microalloyed steel

49MnVS3 (0.47C, 0.34Si, 0.77Mn, 0.053S, 0.12V and 0.0078N) and with a grade similar to SAE 1046 is shown in Figure 9. This illustrates the superiority of the microalloyed steel at low-cycle fatigue and a respectable fatigue strength (high cycle fatigue) considering that the tensile strength of the micro-alloyed steel was slightly lower.(13) The reason for this is that the monotonic tensile properties do not enter into consideration during fatigue, although empirically the fatigue limit is related to tensile strength. The important properties are determined by the cyclic stress-strain curves and these show that the Q+T structures exhibit significantly more cyclic softening than do the ferrite-pearlite structures. As illustrated in Figure 10,(14) the monotonic yield strengths of the Q+T and the microalloyed as-forged steel are about equal. The cyclic stress-strain curves reveal however that the Q+T cyclically softens more and cyclically work hardens less than the as-forged micro-alloyed steel. In other words, the microalloyed steel is capable of carrying more cyclic load at a particular cyclic strain.

The successful application and performance of microalloyed as-forged components illustrate also the role of critical evaluation of the controlling behavior of components in structures. Outright rejection of the microalloyed steel based on lower ductility and impact toughness, which most people do, would not have led to the observed savings in cost and energy. There is probably myriads of situations similar to the situation here where comparable savings in cost and energy can be realized if

the critical evaluation is made.

Summary and Conclusions

An attempt was made to illustrate new applications of vanadium in heat-treated steels as well as in as-forged steels. Both offer tremendous savings in cost, material and energy. In the heat-treated steels, heretofore misconceptions on the influence of vanadium on hardenability were hopefully dispelled both by laboratory results and by the successful commercialization of an economical steel with very good performance. In the as-forged steels, the strengthening effect of vanadium through precipitation of carbo-nitrides was taken advantage of. The successful application of the steel in components illustrate the need to critically evaluate how the component fails in service if we are to save costs and energy.

References

1. SAE Iron and Steel Handbook Supplement HS30, 1980.

2. G. H. Robinson, "The Future of Alloy Steels in the Automobile" p. 1 of "Alloys for the Eighties" R. Q. Barr, Editor, Climax Molybdenum Company, Proceedings of symposium held in Ann Arbor, MI., June 17-18, 1980.

3. Vanadium, Foote Prints, p. 18 Volume 42, No. 1, 1976. (A publication of Foote Mineral Company, Exton, PA.)

4. P. L. Mangonon, "Hardenabilities of Vanadium-Modified 4330 Low Alloy Construction Steels" Journal of Heat Treating 1 No. 4 In Press.

5. P. L. Mangonon, "The Heat-Treatment of Vanadium Modified Alloy Steels" Journal of Metals, June, 1981. In Press.

6. P. L. Mangonon, Relative Hardenabilities and Interaction Effects of Mo and V in 4330 Alloy Steel, submitted for publication to Metallurgical Transactions A.

7. R. A. Grange, Metallurgical Transactions 4A, (1973) pp. 2231-2244.

8. R. B. Bertolo, R. T. Ault and R. H. Cobbett, "A New High Performance, Cost Effective, Carburizing Grade Alloy Steel", SAE Paper 810424, presented at the Annual SAE Congress, Detroit, Michigan, February 23-27, 1981.

9. J. H. Bucher, J. F. Held, & J. F. Butler - "Micro-alloyed Bar Products", SAE Paper 790026, presented at the Annual SAE Congress, Detroit, Michigan, February 26-March 2, 1979.

10. J. H. Bucher, J. H. Held, & J. F. Butler, "Micro-alloyed Bar Products" p. 47 in Vanadium in High Strength Steel, Proceedings of a VANITEC Seminar in Chicago, Illinois, November, 1979.

11. S. Niwa, et. al., Research and Development of Micro-alloyed Medium Carbon Steels, SAE Paper 810426, presented at the Annual SAE Congress, Detroit, Michigan, February 23-27, 1981.

12. C. Razim, Use of Medium Carbon Micro-alloy Steel in Fatigued Strengthened Structural Parts, Metal Progress, May, 1981. p. 50.

13. D. Whittaker, Micro-alloyed Medium Carbon Steels for Forging, Metallurgia, April, 1979, p. 275.

List of Tables & Figures

TABLE I

COMPOSITIONS OF LABORATORY HEATS

GRADE	C	MN	SI	NI	CR	MO	V	PB
6118	0.19	0.63	0.29	0.18	0.62	0.06	0.12	-
4718	0.18	0.84	0.30	1.05	0.49	0.34	-	-
4620	0.18	0.58	0.29	1.85	0.20	0.23	-	-
4320	0.20	0.59	0.30	1.80	0.50	0.23	-	-
NI-CR-V	0.18	0.55	0.22	1.85	0.56	0.03	0.12	-
4815	0.16	0.54	0.28	3.50	0.19	0.22	-	-
3310	0.12	0.48	0.24	3.35	1.45	0.04	-	-
33L10	0.12	0.57	0.30	3.65	1.65	0.07	-	0.22

Table II

Carburizing Cycles

Cycle A - 1650°F (8 Hours) → Oil Quench → Temper, 325°F (1 Hour)
~ 0.95% Carbon Potential

Cycle B - 1700°F (7 Hours) → Oil Quench → Temper, 325°F (1 Hour)
~ 0.85% Carbon Potential

Cycle C - Same as Cycle B plus a Reheat Hardening Cycle

Grade	Reheat Temperautre, °F (1 Hour)
6118	1575
4718, 4320, 4815	1550
4620, Ni-Cr-V	1525
3310, 33L10	1500

Oil Quench and Temper, 325°F (1 Hour)

TABLE III

COMPOSITIONS OF COMMERCIAL HEATS

Grade	C	Mn	Si	Ni	Cr	Mo	Cu	V	Pb
4620	0.18	0.55	0.24	1.75	0.14	0.24	0.14	< 0.01	-
Ni-Cr-V	0.17	0.63	0.27	1.65	0.63	0.04	0.20	0.11	-
33L10	0.13	0.52	0.25	3.13	1.23	0.07	0.29	< 0.01	0.20

TABLE IV

PSEUDOCARBURIZED PROPERTIES OF COMMERCIAL HEATS

Grade	Yield Strength (ksi)	Ultimate Tensile Strength (ksi)	Percent Elongation	Percent Reduction in Area	CVN Impact Energy (ft-lbs)	
					+70°F	-40°F
4620	150.3	211.4	12.5	38.9	36	17
Ni-Cr-V	147.3	200.5	15.0	56.6	47	36
33L10	142.9	187.3	15.0	55.5	32	30

PSEUDOCARBURIZED USING THERMAL HISTORY OF CYCLE B

Table V

Carburized Impact Properties of Commercial Heats

Grade	Unnotched Charpy Impact Energy (ft-lbs)					
	Cycle A		Cycle B		Cycle C	
	+70°F	-40°F	+70°F	-40°F	+70°F	-40°F
4620	19	19	28	19	23	20
Ni-Cr-V	26	13	22	11	30	20
33L10	28	22	38	31	33	24

Table VI

Carburized Fatigue Properties of Commercial Heats

Grade	Endurance Limit (ksi) Cycle A	Endurance Limit (ksi) Cycle B
4620	140	150
Ni-Cr-V	145	157.5

Table VII

Mechanical Properties of As-Forged Microalloyed, and Quench-Tempered Conventional Free-Machining Steels

Steel*	Heat treatment	YS (kgf/mm^2)	TS (kgf/mm^2)	E (%)	R.A. (%)	I (kgfm/cm^2)
S	As forged**	62	92	21	46	42
S48CL	Quenching and Tempered***	64	86	25	56	104
M	As forged**	54	80	23	45	58
S48CLS$_2$	Quenching and Tempered***	60	84	22	51	71

* Compositions:
S: 0.44C-0.55Si-0.81Mn-0.1/V-0.12Pb
S48CL: 0.48C-0.25Si-0.75Mn-0.2Pb
M: 0.36C-0.52Si-0.95Mn-0.10V-0.21Pb-0.106S
S48CLS$_2$: 0.48C-0.25Si-0.75Mn-0.2Pb-0.1S

** Forging conditions:
Heating temp.: 1200°C
Forging temp. (start): 1200°C
Forging temp. (finish): 1000°C
Size (start): 50mm dia. bar
Size (finish): 25mm dia. bar
Cooling after forging: Air cool

YS: 0.2% Proof stress
TS: Tensile strength
E: Elongation
RA: Reduction in area
I: Charpy impact value at room temp. (2mm U notched)

*** Quenching: 850°Cx30min. Oil quench (25mm dia. bar)
Tempering: 600°Cx1hr. Water cool

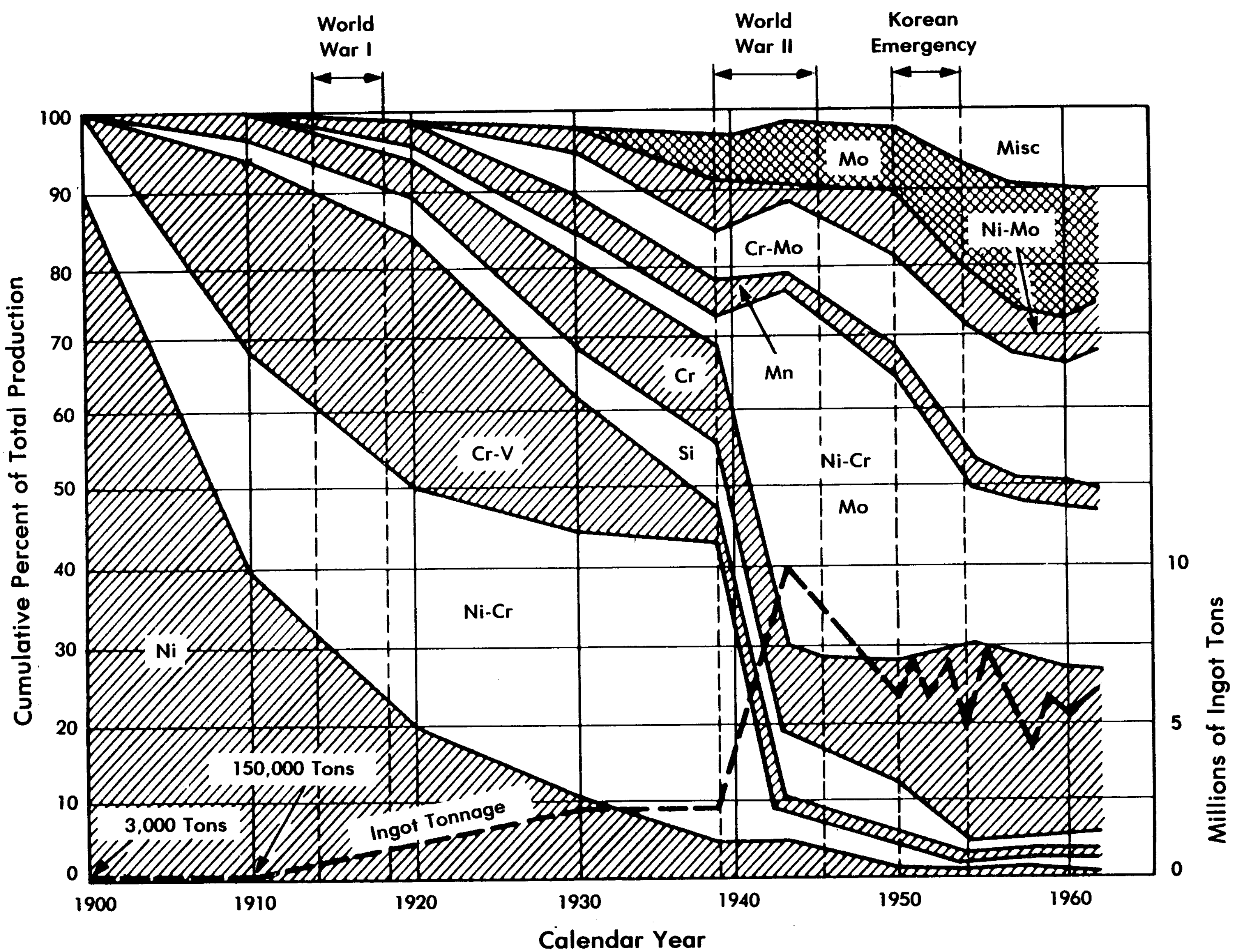


FIG. 1. **Alloy Steel Production in the U.S. Showing Cumulative Percent of Steel Type Produced in a Given Year from 1900.**

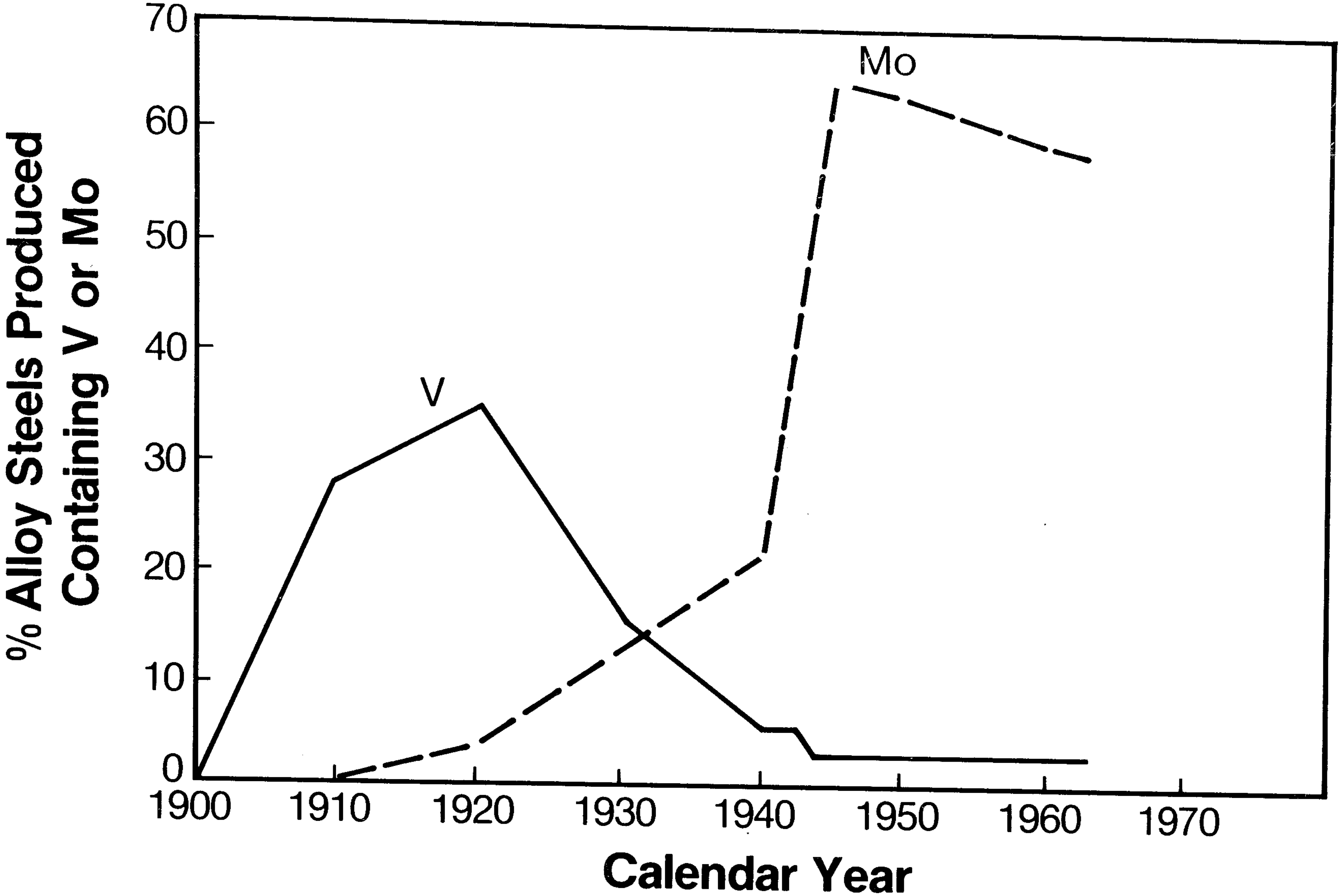


FIG. 2. RELATIVE PERCENT OF ALLOY STEELS PRODUCED CONTAINING V OR MO DURING SAME PERIOD AS FIG. 1.

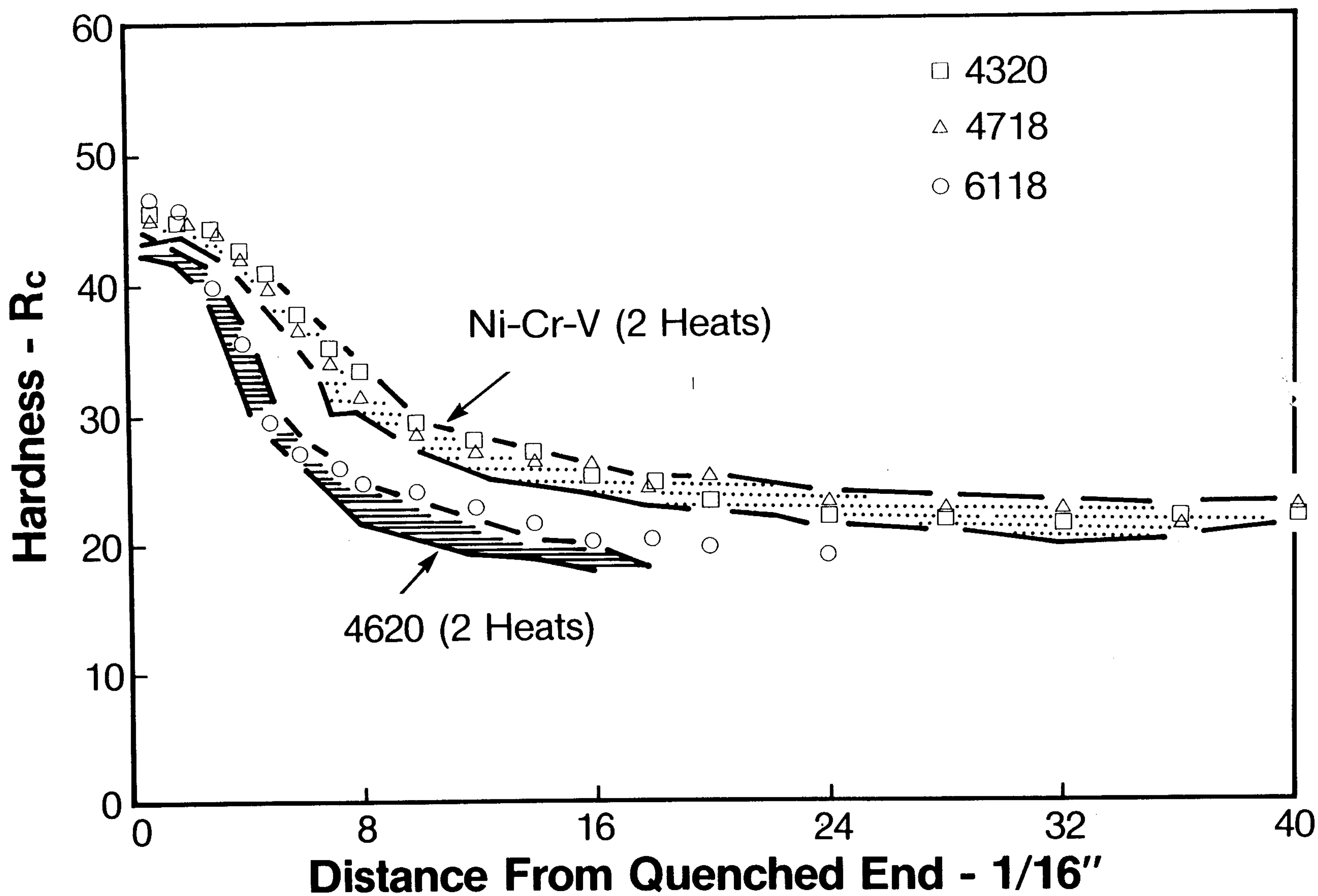


FIG. 3. HARDENABILITY OF 6118, 4620, 4718, 4320 AND NI-CR-V LABORATORY HEATS

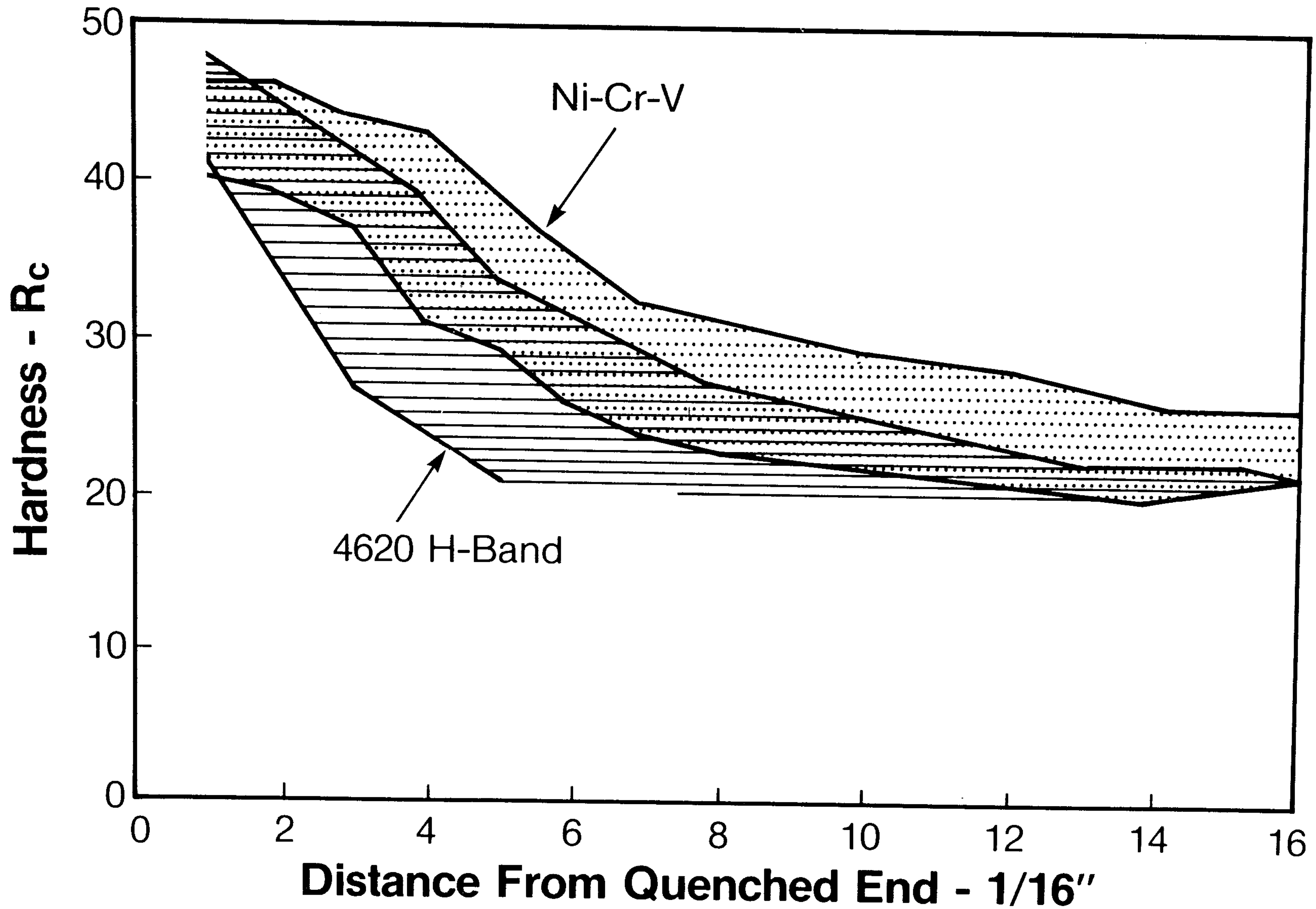


FIG. 4. HARDENABILITY RANGE FOR 15 COMMERCIAL HEATS OF NI-CR-V COMPARED TO THE 4620-H BAND.

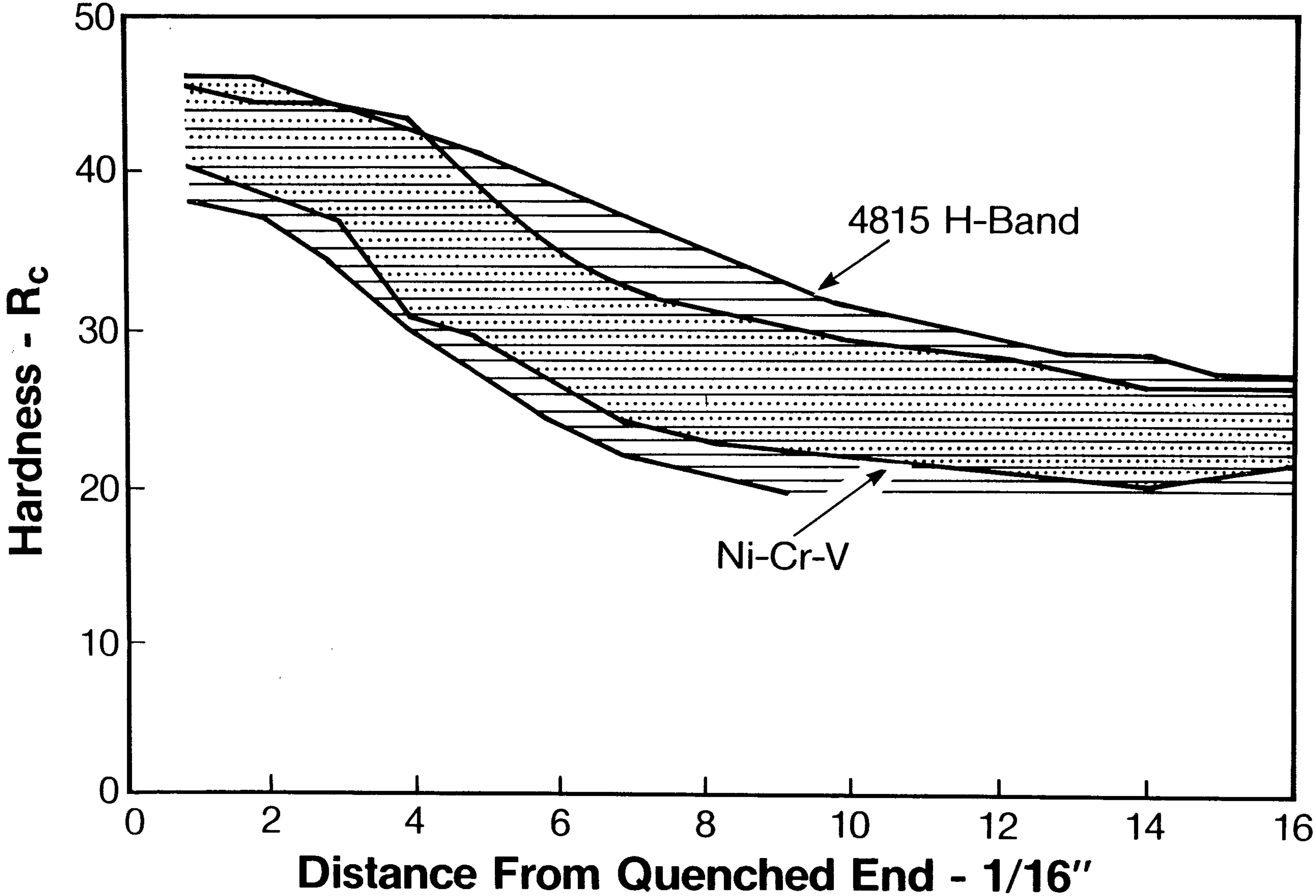
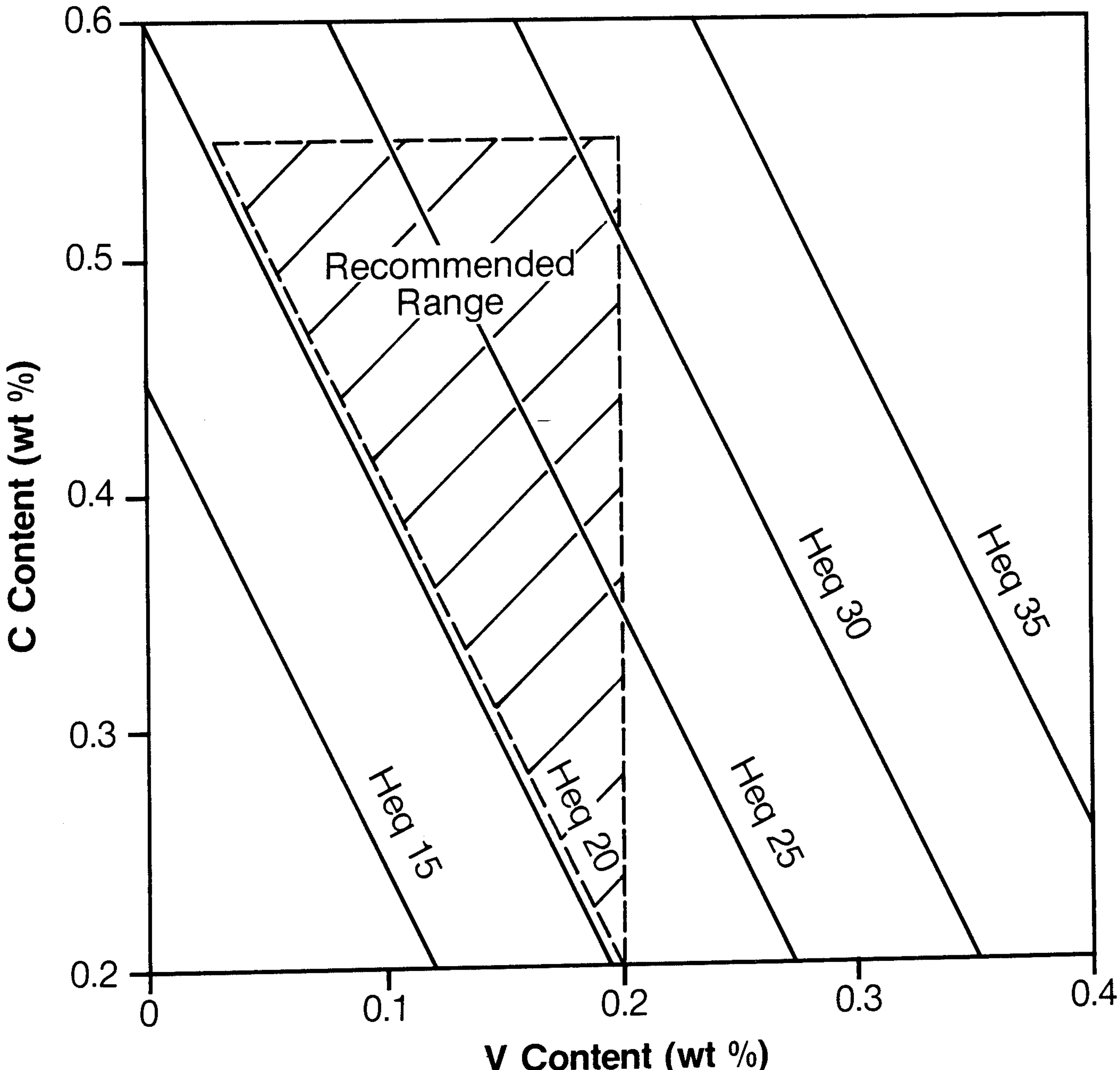


FIG. 5. HARDENABILITY RANGE FOR 15 COMMERCIAL HEATS OF NI-CR-V COMPARED TO THE 4815-H BAND.

FIG. 6

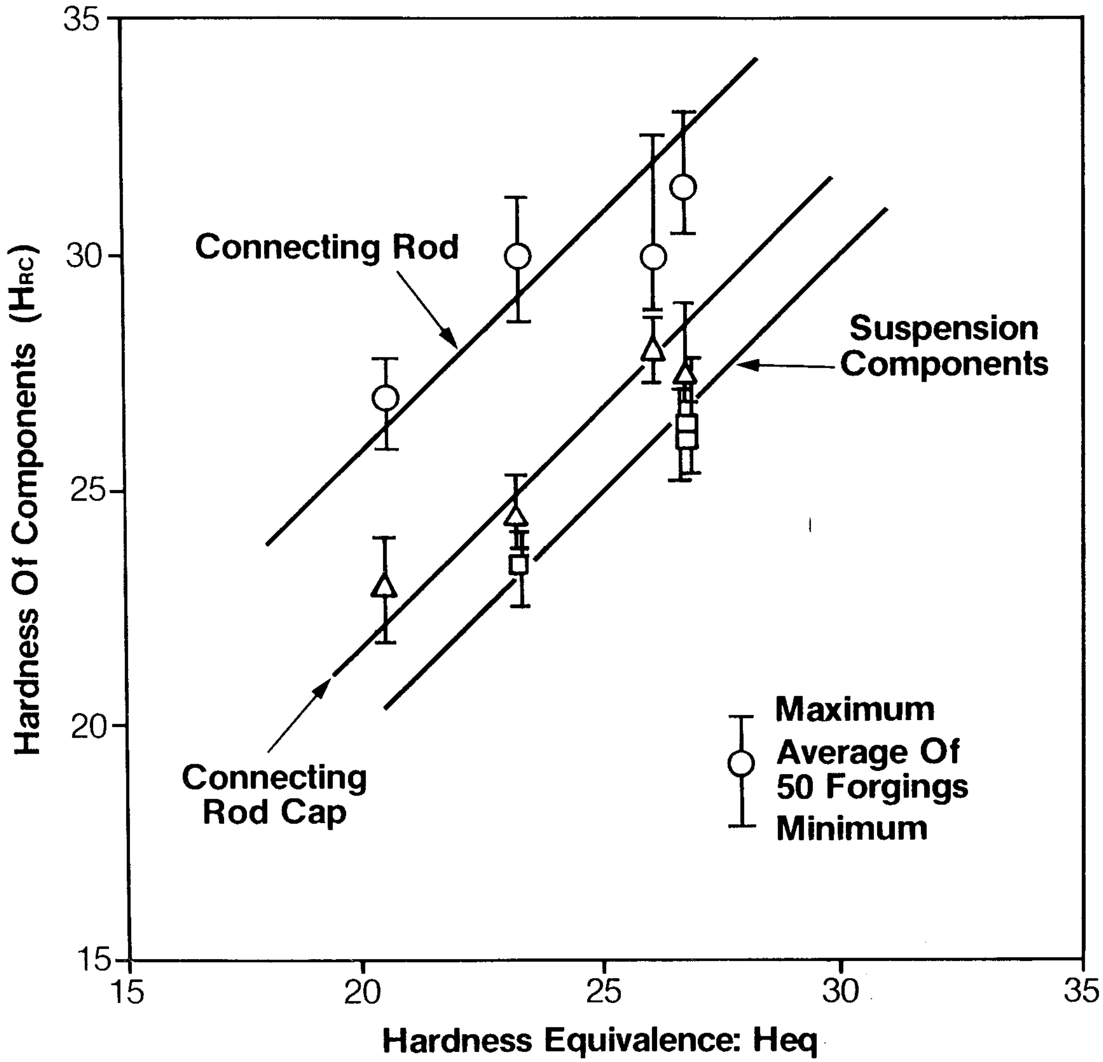
Influence Of C And V Contents On Hardness Equivalence



Note: Other Alloying Elements Si: 0.25%, Mn: 0.75%, N: 0.01%

FIG. 7

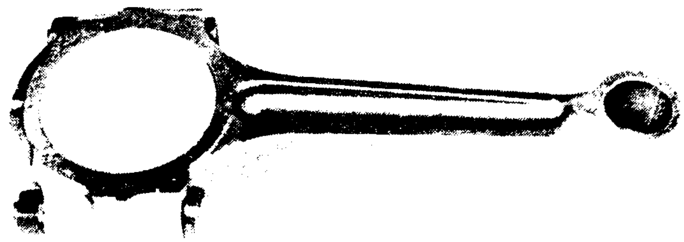
Correlation Of Hardness Equivalence and Hardness Of Actual Components After Forging



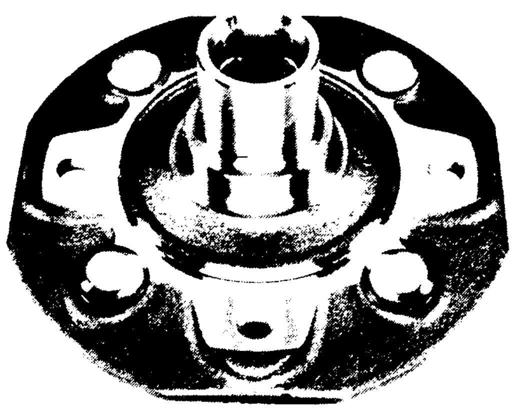
Forging Conditions \ Symbol	○	△	□
Heating Temperature	1250°C	1100°C	1250°C
Cooling After Forging	Air Cool		
Weight	0.7 kg	0.2 kg	1.2-1.5 kg

FIG. 8

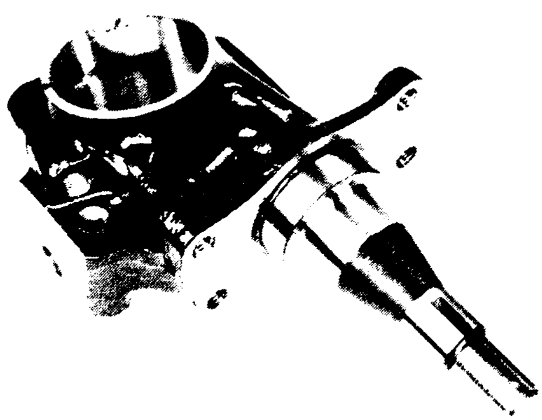
Examples of Forgings of Microalloyed Steels



(a) Connecting rod and connecting rod cap



(b) Suspension component



(c) Suspension component

FIG. 9

**Comparative Fatigue Resistance Of SAE 1046
And 49 MnVS 3 Crankshafts For Diesel Engines.
Minimum Load: 5 kN (1120 lb).**

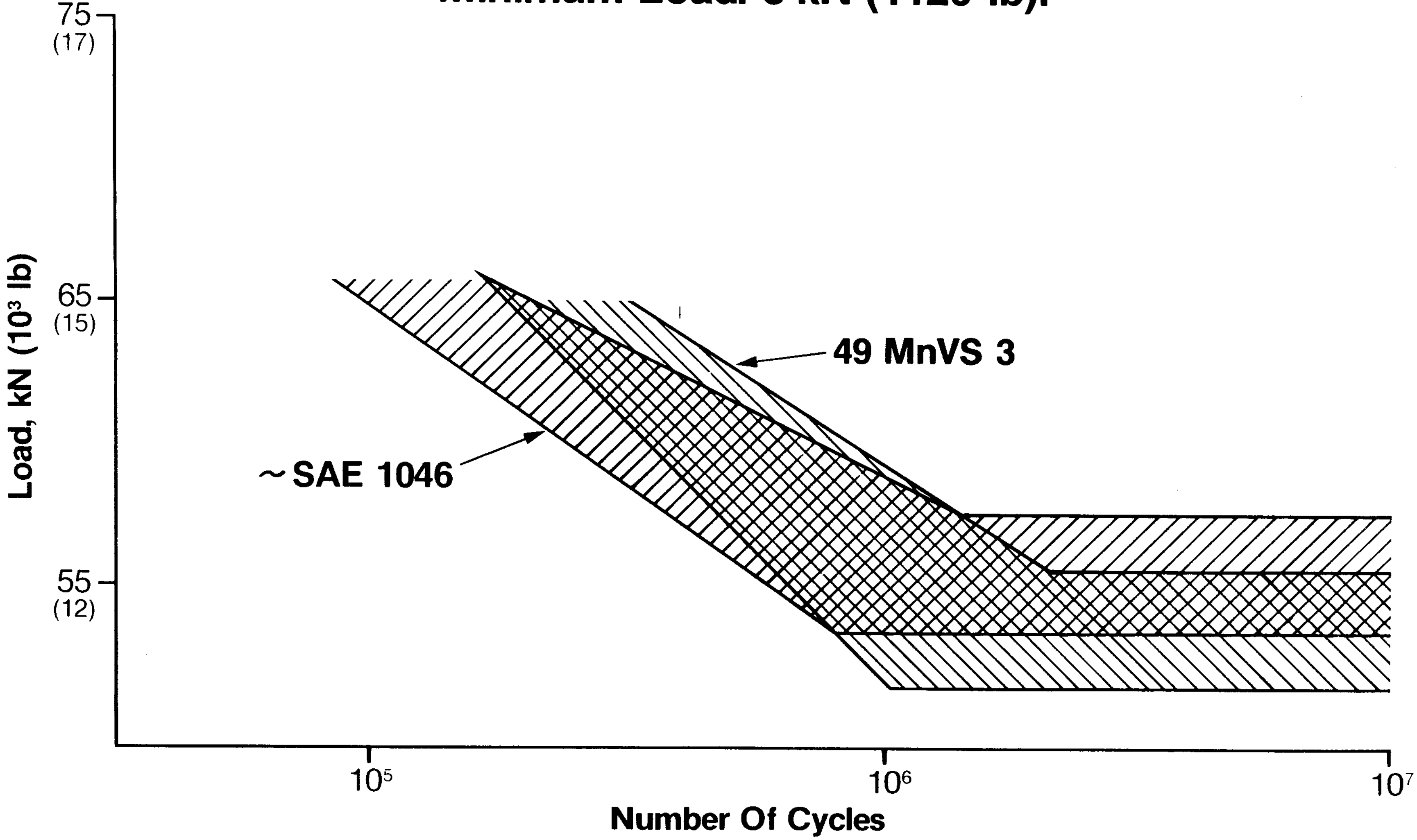
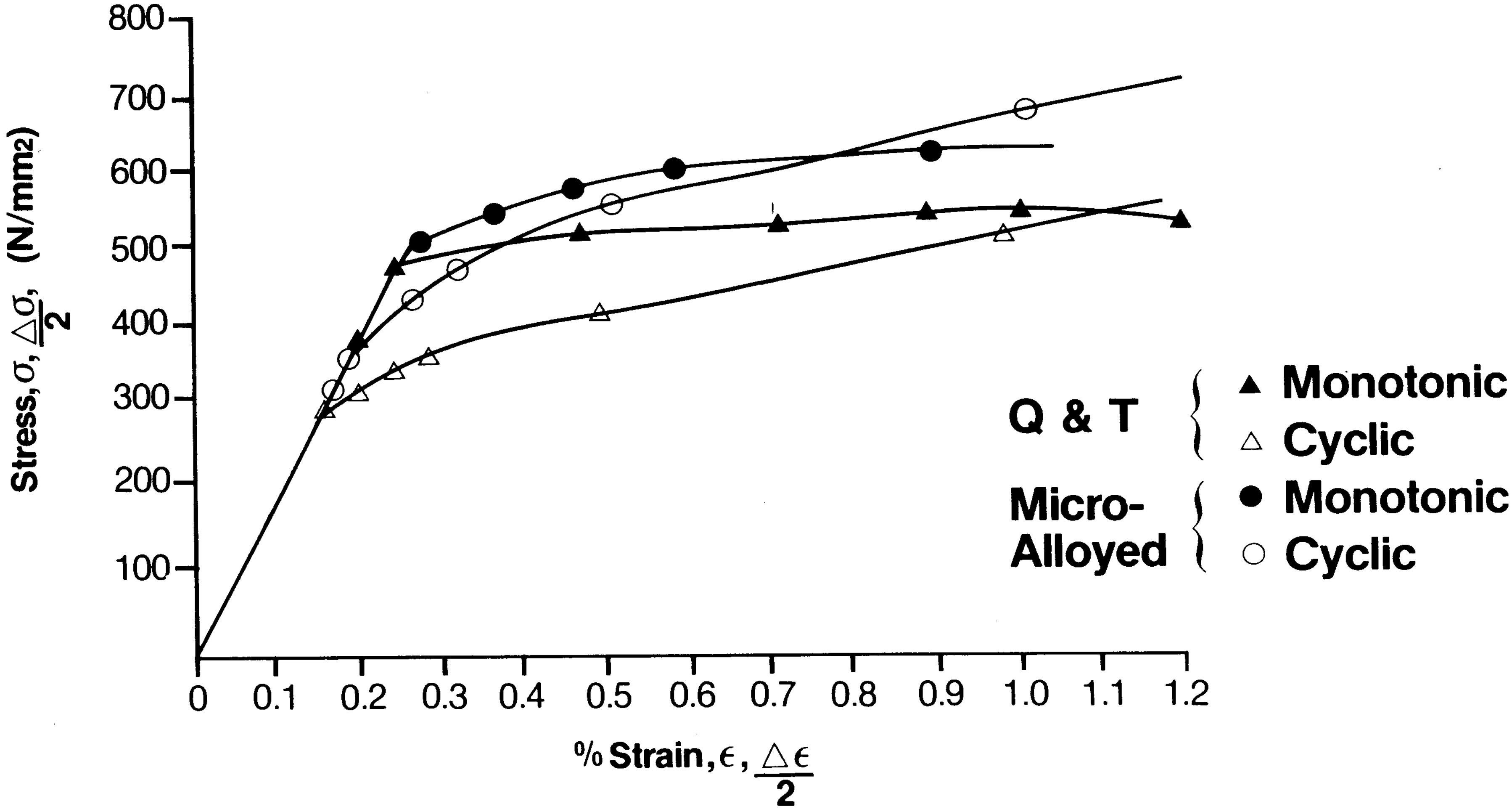


FIG. 10

Cyclic Stress-Strain Curves of Microalloyed Steel and Quenched and Tempered Steel Showing Cyclic Softening Behavior.



NEW RECLAMATION PROCESS FOR CRITICAL METALS

William J. Boesch
Special Metals Inc.

"New Reclamation Process
for
Critical Metals"

Presentation

for
Special Metals Corporation

by

W. J. Boesch
Associate Director - Technology
Special Metals Inc.
at

Workshop on Conservation and Substitution Technology
for
Critical Materials

15-17 June 1981

Vanderbilt University, Nashville, Tennessee

Sponsored

by

U. S. Department of Commerce/NBS

U. S. Department of Interior/Bureau of Mines

Participation

with

U.S. Department of Defense

National Aeronautics and Space Administration

INTRODUCTION

Raw material shortages impact business in three fundamental modes: Economic (can live with); Economic/Geopolitical (can live with, if supply is diverse and available to the country requiring the supply); and Economic/ World Resource (severe problem since this [Tantalum Example] is closest to a depletion problem). Although the general increase in element costs pose some business problems, we can pass those and address the more serious problems. The United States has a very high import reliance on many strategic elements such as chromium and cobalt. Sensitive geopolitical situations can precipitate shortages, may strongly impact the vital interests of the United States and may even threaten National Security. There also exists the imposing specter of a general lack of world resources with elements such as tantalum. This really poses a challenge to the aerospace, petrochemical, and defense-related industries. Conservation is suggested as a means of alleviating the problem. This methodology usually involves restriction in usage and recycling. Current and newly proposed recycling processes have certain inherent shortcomings. Generally, recycling incorporates collection, processing, remelting, and refining of segregated scrap which has chemical formulations compatible with the desired alloy. These techniques usually have minimum flexibility and may inherently introduce contamination and non-compatible alloys which can decrease properties or render the desired alloy useless, especially in high technology applications. Scrap identification, analysis, isolation, and storage difficulties do not create an ideal zero-defect environment. An attractive optional methodology is to utilize reclamation of critical elements. To clarify a point, we must define what we mean by "Recycling" and "Reclamation." Basically we suggest that:

- Recycling involves manufacturing of superalloys, utilizing segregated scrap which has chemical formulations compatible with the desired alloy; whereas,
- Reclamation involves processing of miscellaneous scrap which contains strategic elements to be recovered in pure form.

The development, construction, and operation of an integrated reclamation plant for recovery of strategic elements from industrial waste and scrap could provide the most reliable and flexible supply of critical elements. The attached flow sheets detail a typical operation and summarize the benefits.

PROPOSAL

It is proposed to integrate various metallurgical technologies in the recovery of elemental metals from superalloy and stainless steel scrap. The recovered metals are to be suitable for aircraft, aerospace and other defense-oriented applications. A production-scale process study will demonstrate the technology using commercially available operating equipment. In this way, cost estimates can be derived from production rather than extrapolated pilot plant experience.

Special Metals has been conducting dissolution and extraction experiments at the Arizona Bureau of Geology and Mineral Technology, in conjunction with the University of Arizona. Using Waspaloy grinding dust, a process has been devised to recover cobalt, molybdenum, nickel, and chromium. A pilot plant stage to verify the feasibility of the process is necessary, to verify existing data.

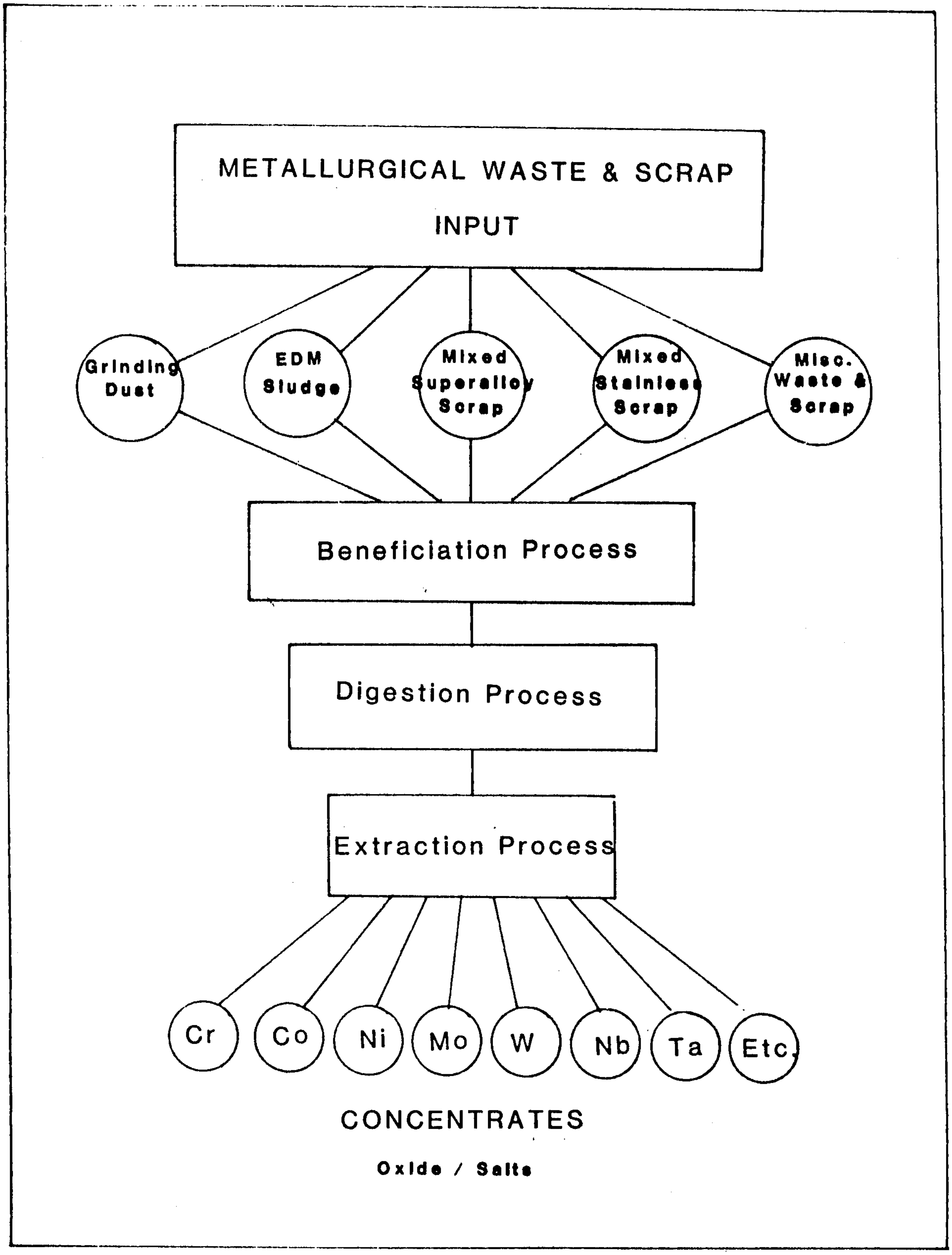
A project team will be formed to carry out the unit operations in sequence. The operations will include furnacing (to result in oxidization and carburization of the scrap),atomization, dissolution, solvent extraction, chemical precipitation, electrowinning, and hydrogen reduction. Where possible, existing commercial equipment will be used. This approach will result in more accurate process parameter evaluation and cost estimates than those extrapolated from prior studies. The metals recovered will be analyzed to verify their suitability for aircraft applications. This suitability will be demonstrated by the evaluation of representative superalloys prepared from the reclaimable metals. A cost effective plant will be designed and constructed.

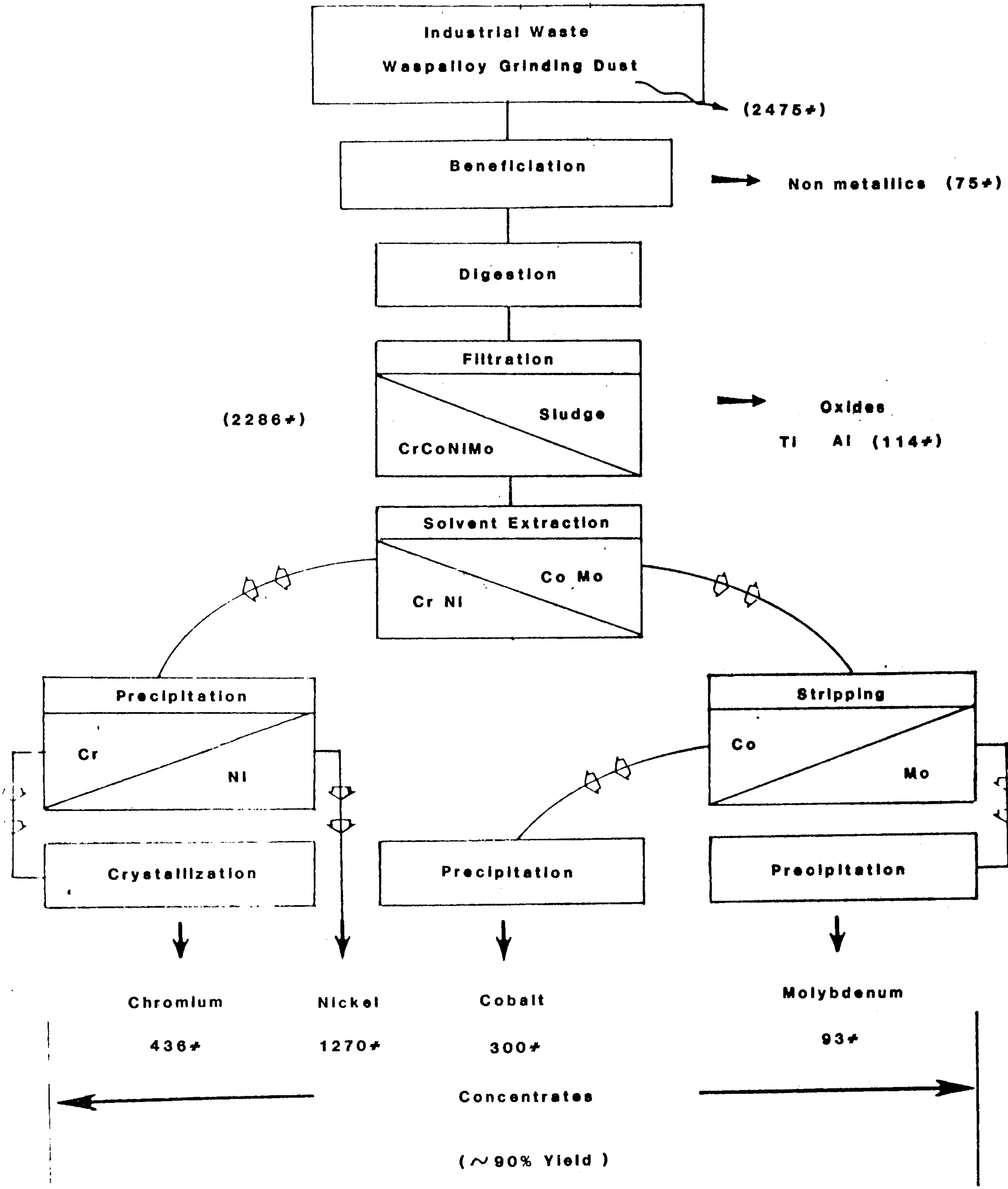
Application of such technologies to superalloy and stainless steel scrap will increase the availability of strategic materials and thereby lessen dependence on foreign imports. Demonstrating that the technique is cost-effective on a production scale is expected to spur the establishment of integrated facilities within the metals industry.

SUMMARY:

Successful completion of the proposal will result in increased availability of strategic materials in elemental form, thus:

- Decrease Import Reliance on Strategic Elements
- Increase the Flexibility for Reclaimed Element Use


METALLURGICAL WASTE & SCRAP
INPUT
Grinding Dust
EDM Sludge
Mixed Superalloy Scrap
Mixed Stainless Scrap
Misc. Waste & Scrap
Beneficiation Process
Digestion Process
Extraction Process
Cr
Co
Ni
Mo
W
Nb
Ta
Etc.
CONCENTRATES
Oxide / Salts


Industrial Waste
Waspalloy Grinding Dust
(2475#)
Beneficiation
Non metallics (75#)
Digestion
Filtration
Sludge
CrCoNiMo
(2286#)
Oxides
Ti Al (114#)
Solvent Extraction
Co Mo
Cr Ni
Precipitation
Cr
Ni
Stripping
Co
Mo
Crystallization
Precipitation
Precipitation
Chromium
436#
Nickel
1270#
Cobalt
300#
Molybdenum
93#
Concentrates
(~90% Yield)

PILOT PLANT STUDY

Estimated Financial Balance

Processing of 2500 lbs. of Waspalloy waste per day for 330 days per year operation

Capital $2,000,000

Operation $3,500,000

Recovered Metal Values

Chromium (72 tons ppt.)

Nickel (210 tons metal)

Cobalt (50 tons metal)

Molybdenum (15 tons ppt.) $4,600,000

THE ROLE OF COMPOSITES IN SUBSTITUTION, CONSERVATION AND DISPLACEMENT OF CRITICAL MATERIALS

Alfred E. Brown
Celanese Corp.

PL-48502

KEYNOTE ADDRESS

THE ROLE OF COMPOSITES IN SUBSTITUTION, CONSERVATION AND DISPLACEMENT OF CRITICAL MATERIALS

BY

DR. ALFRED E. BROWN
DIRECTOR, SCIENTIFIC AFFAIRS
CELANESE CORPORATION

PRESENTED AT

THE WORKSHOP ON CONSERVATION AND SUBSTITUTION TECHNOLOGY FOR CRITICAL MATERIALS

VANDERBILT UNIVERSITY
NASHVILLE, TENNESSEE

JUNE 17, 1981

THIS MORNING I'D LIKE TO DISCUSS THE ROLE OF COMPOSITES IN SUBSTITUTION, CONSERVATION AND DISPLACEMENT OF CRITICAL MATERIALS.

AS WE'RE LEARNING IN THIS WORKSHOP, THERE ARE SEVERAL ROUTES TO REDUCE THE DEMAND ON CRITICAL MATERIALS. ONE SUCH ROUTE IS THROUGH THE REPLACEMENT OF METALS WITH STRUCTURAL COMPOSITES. SINCE THE STRUCTURAL COMPOSITES INDUSTRY IS ENTERING A PERIOD OF EXPLOSIVE GROWTH (COMPOUNDED GROWTH RATES OF 25-30%/YEAR ARE ANTICIPATED FOR THE 80'S) THE POTENTIAL IMPACT ON CONSERVATION OF CRITICAL MATERIALS IS VERY SIGNIFICANT. THEREFORE, IT'S IMPORTANT TO UNDERSTAND THE MAGNITUDE AND RAMIFICATIONS OF COMPOSITE REPLACEMENT IN ORDER TO PROJECT THE IMPACT ON MATERIALS CONSERVATION. TO ACQUIRE THIS UNDERSTANDING, IT'S NECESSARY TO APPRECIATE THE NATURE AND CHARACTERISTICS OF THE UNDERLYING COMPOSITES INDUSTRY.

THE RATIONALE FOR THE RAPID GROWTH OF THE COMPOSITE INDUSTRY IS THE URGENT NEED FOR MORE FUEL EFFICIENT TRANSPORTATION AND THE PROVEN ABILITY TO SUBSTITUTE LIGHTWEIGHT COMPOSITE STRUCTURE FOR HEAVIER TRADITIONAL METALS BECAUSE OF THE HIGHER PERFORMANCE PROPERTIES OF GRAPHITE COMPOSITES. THIS REPLACEMENT OF METALS WITH COMPOSITES PROVIDES TWO ROUTES TO REDUCE DEMAND FOR CRITICAL MATERIALS. THE FIRST IS DIRECT SUBSTITUTION OF COMPOSITES FOR CRITICAL METAL STRUCTURE, WHEREAS, THE SECOND RESULTS FROM SECONDARY CASCADING EFFECTS WHEN A COMPONENT WITHOUT CRITICAL MATERIALS IS DIRECTLY DOWNSIZED. HAVING

INDICATED THE RELEVANCE OF COMPOSITES IN REDUCING THE DEMAND FOR CRITICAL MATERIALS, I'D LIKE TO REVIEW BRIEFLY COMPOSITES AS REPLACEMENT MATERIALS.

IN DISCUSSING COMPOSITES AND THEIR ROLE AS SUBSTITUTION MATERIALS, I THINK IT'D BE BENEFICIAL TO START OFF WITH A GENERAL REVIEW OF THE USE AND PERFORMANCE CHARACTERISTICS OF COMPOSITES FOLLOWED BY A DISCUSSION OF THE GENERAL NATURE OF THE COMPOSITE INDUSTRY. I THEN INTEND TO DISCUSS COMPOSITE END-USE APPLICATIONS IN THE AEROSPACE/AIRCRAFT INDUSTRY AND IN VARIOUS AUTOMOTIVE/ INDUSTRIAL APPLICATIONS. THE PRIMARY THRUST OF MY COMMENTS IN THIS SECTION, HOWEVER, WILL BE DIRECTED TOWARDS AEROSPACE/AIRCRAFT BECAUSE THAT'S WHERE THE MAJOR GROWTH AND REPLACEMENT OPPORTUNITIES WILL OCCUR IN THE 1980'S. SIGNIFICANT GROWTH IN THE AUTO/ INDUSTRIAL SECTOR IS NOT PROJECTED TO OCCUR UNTIL THE LATE 1980'S.

THE FIRST SLIDE (FIGURE 1) HAS A DEFINITION FOR STRUCTURAL COMPOSITES. BASICALLY, STRUCTURAL COMPOSITES ARE PRODUCTS WHICH COMBINE VERY HIGH STRENGTH AND STIFFNESS, LOW DENSITY FIBER REINFORCEMENTS (E.G., CARBON, ARAMID, GLASS, BORON) WITH CONVENTIONAL POLYMERS OR METALS (E.G., EPOXY, POLYESTER, POLYIMIDE, ALUMINUM) TO FORM STRUCTURAL MATERIALS WITH UNIQUE PROPERTY CHARACTERISTICS. THE HIGH FIBER LOADINGS (TYPICALLY 50-70% BY WEIGHT, INDICATED ON THE SLIDE), ARE REQUIRED TO SIMULTANEOUSLY MAXIMIZE PERFORMANCE LEVELS AND WEIGHT SAVINGS.

THE MOTIVATION BEHIND THE BROAD BASED APPEAL THAT STRUCTURAL COMPOSITES HAVE OBTAINED IN RECENT YEARS IS SUMMARIZED IN THE NEXT SLIDE (FIGURE 2). FIRST, COMPOSITES HAVE UNIQUE PERFORMANCE CHARACTERISTICS WHEN COMPARED TO METALS AND PERFORMANCE HAS BEEN THE DRIVING FORCE IN THE SUBSTITUTION OF METALS BY STRUCTURAL COMPOSITES. THEY COMBINE THE IMPORTANT MECHANICAL PROPERTIES OF HIGH SPECIFIC STRENGTH AND SPECIFIC STIFFNESS, VERY GOOD DYNAMIC RESPONSE AND EXCELLENT CHEMICAL PROPERTIES SO THAT THEY HAVE INHERENT PERFORMANCE ADVANTAGES OVER MOST OTHER MATERIALS. TYPICAL SECONDARY PROPERTIES OF INTEREST INCLUDE FATIGUE RESISTANCE, CORROSION RESISTANCE, AND LOW THERMAL EXPANSION. THE SPECIFIC SET OF PROPERTIES AVAILABLE, DEPENDS, OF COURSE, ON THE COMBINATION OF FIBER AND MATRIX UTILIZED. SECOND, COMPOSITES OFFER DESIGN FLEXIBILITY AND SIMPLIFICATION. BY VIRTUE OF THEIR ANISTROPIC NATURE, HIGH PHYSICAL PROPERTIES ARE DEVELOPED IN THE COMPOSITE'S FIBER DIRECTION DESPITE THE RELATIVELY LOW PROPERTIES OF THE MATRIX RESIN ALONE. COMPOSITE DESIGN AND FABRICATION CAN UTILIZE FIBER ORIENTATION AND LAYERING SEQUENCES TO GET MAXIMUM PERFORMANCE OUT OF THE MINIMUM AMOUNT OF MATERIAL. THIRD, COMPOSITES HAVE ESTABLISHED THE NECESSARY DATABASE FOR DEMONSTRATED PERFORMANCE RELIABILITY AND COST EFFECTIVENESS IN THE AEROSPACE/AIRCRAFT INDUSTRY. A MAJOR TRANSFORMATION IN THE USE OF STRUCTURAL MATERIALS IS NOW OCCURRING WITHIN THE AEROSPACE INDUSTRY AS THE NEED FOR MORE FUEL EFFICIENT PLANES

GROWS. I'LL SAY MORE ON THIS SUBJECT LATER. FINALLY, COMPOSITES ALSO OFFER POTENTIAL FOR THE INDUSTRIAL/AUTOMOTIVE MARKET, BUT MATERIAL ACCEPTANCE ON A LARGE SCALE IS STILL SEVERAL YEARS AWAY. KEY ISSUES TO BE ADDRESSED HERE ARE HIGH SPEED INDUSTRIAL PROCESSING AND RAW MATERIAL ECONOMICS.

THE NEXT SLIDE (FIGURE 3) ILLUSTRATES THE EXCELLENT SPECIFIC COMPOSITE PROPERTIES WHICH I ALLUDED TO A FEW MOMENTS AGO. IN THIS CHART, SPECIFIC TENSILE STRENGTH AND SPECIFIC TENSILE MODULUS FOR A NUMBER OF ORGANIC MATRIX COMPOSITE MATERIALS AND METALS ARE SHOWN. NOTE THAT THE DEFINITION OF A SPECIFIC COMPOSITE PROPERTY IS THE ABSOLUTE VALUE OF THE PROPERTY DIVIDED BY THE MATERIAL'S DENSITY. THE SPECIFIC TENSILE STRENGTHS OF CARBON, KEVLAR, AND CONTINUOUS GLASS/EPOXY SYSTEMS ARE FAR SUPERIOR TO ANY OTHER MATERIALS SHOWN ON THE CHART. WITH REGARD TO SPECIFIC TENSILE MODULUS, HOWEVER, CARBON FIBER/EPOXY SYSTEMS ARE CLEARLY UNIQUE AND THE SYSTEM OF CHOICE. THE BAR CHART ESTABLISHES AT LEAST PART OF THE TECHNICAL JUSTIFICATION FOR COMPOSITE SUBSTITUTION IN THAT IT DRAMATICALLY ILLUSTRATES HOW COMPOSITE MATERIALS CAN COMPETE EFFECTIVELY AGAINST STEEL AND ALUMINUM ON A PERFORMANCE/WEIGHT BASIS. ALTHOUGH THE ABOVE BAR CHART DIDN'T ILLUSTRATE THE ADVANTAGES OF METAL MATRIX COMPOSITES, THE SPECIFIC PROPERTIES ARE INTERMEDIATE BETWEEN THOSE OF THE PURE METALS AND OF THE ORGANIC MATRIX COMPOSITES. THIS ILLUSTRATES THAT THE METAL MATRIX COMPOSITES CAN ALSO COMPETE EFFECTIVELY WITH METALS ON A

PERFORMANCE/WEIGHT BASIS BUT THE MAGNITUDE OF THE ADVANTAGE DEPENDS UPON THE DENSITY OF THE MATRIX MATERIAL. CLEARLY, METAL MATRIX COMPOSITES ARE UTILIZED WHERE HIGH TEMPERATURE PERFORMANCE IS AT A PREMIUM.

CARBON FIBER COMPOSITES ARE ONE OF THE FASTEST GROWING SEGMENTS OF THE HIGH PERFORMANCE COMPOSITE BUSINESS. THIS GROWTH RATE IS BEING FUELED BY THEIR INCREASING ACCEPTANCE IN THE AEROSPACE INDUSTRY AND BY THE STANDARDIZATION IN PRODUCT QUALITY AND PRODUCT PERFORMANCE WHICH RESULTED FROM LARGE SCALE MANUFACTURE. THE NEXT SLIDE (FIGURE 4) SHOWS SOME OF THE KEY PERFORMANCE FACTORS IMPACTING THE USE OF CARBON FIBER COMPOSITES. ON THE LEFT HAND SIDE, I HAVE LISTED THE MAJOR PRODUCT ADVANTAGES AND ON THE RIGHT HAND SIDE I HAVE HIGHLIGHTED SOME OF THE CRITICAL ISSUES WHICH MUST BE ADDRESSED IF CARBON FIBER IS TO ACHIEVE IT'S LONG-TERM POTENTIAL. COUPLING LOW WEIGHT -- COMPOSITE PARTS TYPICALLY WEIGH 1/5 THAT OF THE WEIGHT OF A STEEL PART -- WITH HIGH STRENGTH AND STIFFNESS, GIVES THE SPECIFIC PERFORMANCE ADVANTAGES ALREADY MENTIONED. FATIGUE RESISTANCE IS ANOTHER CHARACTERISTIC WHICH IS HIGHLY DESIRABLE. AIRCRAFT LIFE, AS MANY OF YOU KNOW, IS DICTATED BY THE FATIGUE LIFE OF THE METAL STRUCTURE. OF COURSE, HELICOPTER BLADES FALL INTO THE SAME CATEGORY. THE OTHER ADVANTAGES (VIBRATION DAMPENING, CORROSION RESISTANCE, FRICTION AND WEAR CHARACTERISTICS, ELECTRICAL CONDUCTIVITY) ARE OFTEN REFERRED TO AS SECONDARY PROPERTIES, BUT EACH CAN OFFER ITS UNIQUE SATISFACTION IN A

GIVEN APPLICATION. REGARDING PERFORMANCE ISSUES THE TWO OF IMMEDIATE CONCERN TO THE AEROSPACE INDUSTRY AND OF GROWING CONCERN TO THE AUTOMOTIVE INDUSTRY ARE COMPOSITE DURABILITY AND REPAIRABILITY. THESE ISSUES NEED TO BE STUDIED MUCH MORE EXTENSIVELY IN THE COMING YEARS, AND THE ULTIMATE OUTCOME COULD EFFECT THE TIMING AND EXTENT TO WHICH COMPOSITES PENETRATE THESE KEY INDUSTRIES. THE ISSUE OF IMPACT, OR DAMAGE TOLERANCE IS GERMANE TO BOTH THE AEROSPACE AND AUTOMOTIVE INDUSTRIES. THE AREA IS ACTIVELY BEING PURSUED AT THE PRESENT TIME FOR PRIMARY COMMERCIAL AIRCRAFT STRUCTURES AND SIGNIFICANT ADVANCES IN THE TECHNOLOGY SHOULD BE FORTHCOMING IN THE NEAR FUTURE. RECYCLING IS AN ISSUE PRIMARILY RELATED TO THE AUTOMOTIVE INDUSTRY, AND IT ALSO NEEDS MUCH MORE STUDY IN THE COMING YEARS.

THE NEXT SLIDE (FIGURE 5) ILLUSTRATES THE PROCESS FOR MAKING LAMINATED COMPOSITE STRUCTURES. HIGH PERFORMANCE, CONTINUOUS FIBERS, OR WOVEN FABRICS, ARE IMPREGNATED WITH EITHER ORGANIC OR METAL MATRICES TO YIELD ANISOTROPIC, PRE-IMPREGNATED TAPES OR BROADGOODS. THE PRE-PREG MATERIAL IS THEN "LAYED-UP" IN A PREDETERMINED LAYERING SEQUENCE, PLACED IN A MOLD, AND CURED WITH HEAT AND PRESSURE. DEPENDING UPON THE KIND OF FIBER USED AND THE LAYUP ANGLES, IT'S POSSIBLE TO GET A COMPOSITE AS STIFF AS BERYLLIUM OR AS STRONG AS THE HIGHEST STRENGTH STEEL.

THE NEXT SLIDE (FIGURE 6) SERVES TO GIVE A CAPSULE SUMMARY OF THE KEY CHARACTERISTICS OF THE STRUCTURAL COMPOSITES INDUSTRY. AS YOU CAN SEE, A 5 BILLION DOLLAR METAL SUBSTITUTION POTENTIAL HAS BEEN IDENTIFIED WITH THE MAJOR END-USE APPLICATIONS BEING AIRCRAFT/AEROSPACE, RECREATION, INDUSTRIAL, AND AUTOMOTIVE. OVER THE NEXT TEN YEARS, AEROSPACE/AIRCRAFT WILL REPRESENT APPROXIMATELY 50% OF THE TOTAL COMPOSITE BUSINESS. THEREFORE, THIS IS THE PRIMARY END-USE AREA WHERE COMPOSITES WILL HAVE A SIGNIFICANT IMPACT ON CRITICAL MATERIAL USAGE IN THE 80'S. THE OVERALL INDUSTRY HAS GENERALLY BEEN CHARACTERIZED AS HAVING HIGH TECHNOLOGY, HIGH VALUE ADDED PRODUCTS, AND HIGH CAPITAL INTENSITY. THE OBVIOUS IMPLICATION HERE IS THAT SEVERAL LARGE CORPORATIONS WITH SUBSTANTIAL CAPITAL RESOURCES AND TECHNOLOGY BASES WILL BECOME DOMINANT FACTORS IN THIS BUSINESS. THIS IS AN IMPORTANT PARAMETER WHEN CONSIDERING CRITICAL MATERIAL SUBSTITUTION.

HAVING DESCRIBED THE GENERAL CHARACTERISTICS OF COMPOSITE MATERIALS AS WELL AS THE NATURE AND CONDITION OF THE EMERGING INDUSTRY, I'D NOW LIKE TO PRESENT AN OVERVIEW OF AEROSPACE AND NON-AEROSPACE APPLICATIONS. THE OTHER TWO SPEAKERS THIS MORNING WILL DESCRIBE IN MORE DETAIL THE POTENTIAL FOR COMPOSITE SUBSTITUTION IN THESE INDUSTRIES. FIRST, LET'S EXAMINE COMPOSITES' UTILIZATION IN AIRCRAFT WHERE THE PRESENT RAPID GROWTH IS OCCURRING.

A MAJORITY OF THE DEVELOPING AIRCRAFT APPLICATIONS DO NOT REQUIRE VERY HIGH TEMPERATURE PERFORMANCE AND HENCE CAN BE SATISFIED WITH ORGANIC MATRIX COMPOSITES. HOWEVER, AS I'LL ILLUSTRATE LATER IN DISCUSSING TYPICAL AIRCRAFT APPLICATIONS, THE USE OF CRITICAL MATERIALS SUCH AS TITANIUM IN ENGINE APPLICATIONS IS DECREASED PRINCIPALLY BY CASCADE EFFECTS ASSOCIATED WITH DOWN SIZING OF THE OVERALL STRUCTURE INCLUDING THE ENGINE. IT'S NOTEWORTHY NONETHELESS, THAT EXTENSIVE EFFORTS ARE BEING EXPENDED TO DEVELOP METAL MATRIX COMPOSITES FOR HIGH TEMPERATURE APPLICATIONS. IN THIS NEXT SLIDE (FIGURE 7) ARE LISTED THE TYPES OF SYSTEMS CURRENTLY UNDER DEVELOPMENT. AS CAN BE SEEN, CARBON, BORON, SILICON CARBIDE AND ALUMINA FIBERS ARE BEING COMBINED WITH METALLIC MATRICES SUCH AS ALUMINUM AND MAGNESIUM. TUNGSTEN IS ALSO OF INTEREST. THESE METAL MATRIX FIBROUS COMPOSITES CAN DIRECTLY SUBSITUTE FOR CRITICAL METAL STRUCTURES AND THUS ALLEVIATE PRESSURE ON AVAILABLE VOLUMES. A SEPARATE EXAMPLE OF CRITICAL MATERIAL SUBSTITUTION IS THE REPLACEMENT OF ALLOYS IN CERTAIN LOW THERMAL EXPANSION APPLICATIONS BY GY-70 GRAPHITE COMPOSITES.

THE NEXT SLIDE (FIGURE 8) HIGHLIGHTS, IN GENERAL, THE TECHNICAL AND ECONOMIC IMPACT OF ADVANCED COMPOSITES UTILIZATION IN AIRCRAFT. THE FIRST POINT TO BE ADDRESSED IS THE SIGNIFICANT WEIGHT SAVINGS DEMONSTRATED WITH COMPOSITES. FOR COMMERCIAL AIRCRAFT, THIS TRANSLATES DIRECTLY TO FUEL SAVINGS, LOWER OPERATING COSTS AND INCREASED PROFITS. COMMERCIAL TRANSPORTS

HAVE EXTREMELY HIGH LIFE TIME MILEAGES, E.G., 20-50MM MILES. HIGH MILEAGE COMBINED WITH REDUCED FUEL CONSUMPTION ENABLES REDUCTIONS IN LIFE-TIME OPERATING COSTS OF SEVERAL HUNDRED DOLLARS PER POUND OF WEIGHT SAVED. FOR MILITARY AIRCRAFT, THE WEIGHT SAVED TRANSLATES TO IMPROVED PERFORMANCE IN BOTH MANEUVERABILITY AND RANGE. IN BOTH MILITARY AND COMMERCIAL AIRCRAFT, SIGNIFICANT REDUCTIONS IN MANUFACTURING COSTS ARE ACHIEVED THROUGH PARTS CONSOLIDATION, WHICH IN TURN LEADS TO FURTHER WEIGHT REDUCTIONS THROUGH THE ELIMINATION OF FASTENERS.

IN THE NEXT SLIDE (FIGURE 9), IS SHOWN THE INCREASE IN FUEL PRICES EXPERIENCED BY THE COMMERCIAL TRANSPORT INDUSTRY IN THE 1973 TO 1980 TIME FRAME. MORE THAN A SEVEN-FOLD RISE IN PRICE HAS OCCURRED. AT THE CURRENT TIME, IN EXCESS OF 50% OF THE DIRECT OPERATING COST OF COMMERCIAL CARRIERS IS DIRECTLY ATTRIBUTED TO FUEL CONSUMPTION. THIS CLEARLY ACCOUNTS FOR INDUSTRY INTEREST IN THE WEIGHT REDUCTION AND FUEL CONSERVATION OFFERED BY ADVANCED COMPOSITES.

IN RECOGNITION OF THE POTENTIAL ECONOMIES AND CONSERVATION WHICH COULD BE REALIZED BY WEIGHT REDUCTION OF COMMERCIAL TRANSPORTS, NASA HAS FUNDED A PART OF THE AIRCRAFT ENERGY EFFICIENCY OR ACEE PROGRAM IN WHICH MILLIONS OF DOLLARS HAVE BEEN SPENT TO STIMULATE FUEL-SAVING DEVELOPMENTS. THE NEXT SLIDE (FIGURE 10) ILLUSTRATES THE EFFECT OF REDUCTION IN

AIRCRAFT WEIGHT ON OPERATING COSTS. BOTH IMPROVEMENTS IN DIRECT OPERATING COSTS AND IN FLEET LIFETIME OPERATING COSTS ARE SHOWN. IT'S IMPORTANT TO NOTE THAT UTILIZATION OF COMPOSITES IN EMPENNAGE AND SECONDARY STRUCTURES HAS A REAL, BUT MINOR, EFFECT IN REDUCING OPERATING EXPENSES BY SLIGHTLY LESS THAN 1% BECAUSE ONLY 3% OF THE STRUCTURE WEIGHT IS INVOLVED IN THESE APPLICATIONS. HOWEVER, WHEN PRIMARY STRUCTURES SUCH AS WING AND FUSELAGE ELEMENTS ARE SUBJECT TO MATERIAL SUBSTITUTION, THE OPERATING COSTS ARE REDUCIBLE BY MORE THAN 6%. AS ONE BECOMES EVEN MORE CONFIDENT IN THE PERFORMANCE AND RELIABILITY OF COMPOSITES, THEN THESE OPERATING COST REDUCTIONS CAN APPROACH OR EVEN EXCEED 10%. IN THIS CASE, SUBSTITUTION FOR METAL IN APPROXIMATELY 50% OF THE STRUCTURE IS PROJECTED. IT MUST, OF COURSE, BE POINTED OUT THAT A PORTION OF THE REPLACED METAL CAN BE TITANIUM WHICH IS ON THE CRITICAL MATERIALS LIST.

THE WEIGHT AND FUEL SAVINGS WHICH CAN BE ACHIEVED BY MATERIALS SUBSTITUTION ARE NOT SIMPLY STATED. SINCE THERE ARE CASCADE EFFECTS INVOLVED, IT'S WORTHWHILE EXAMINING THE EFFECTS OF SUBSTITUTION ONLY AND THEN SUBSTITUTION ACCOMPANIED BY DOWN-SIZING OF THE TRANSPORT. IN THE NEXT SLIDE (FIGURE 11) ARE SHOWN THE GROSS TAKE-OFF WEIGHTS FOR THE ALL-METAL PLANE WHEREIN THE DIRECT EMPTY WEIGHT IS SEPARATELY IDENTIFIED. CHANGES IN THE STRUCTURAL WEIGHT WITHOUT CORRESPONDING DOWN-SIZE OF THE CRAFT LEADS TO A FUEL SAVINGS OF APPROXIMATELY 6%. HOWEVER, AS NOTED ON THE FAR RIGHT WHEN CASCADING EFFECTS ARE BROUGHT INTO PLAY, THEN TOTAL FUEL SAVINGS ARE ENHANCED TO THE 12 TO 15% LEVEL.

WHILE IT'S FAIR TO SPEAK IN GENERALITIES, A FEW SPECIFIC EXAMPLES PUBLICIZED BY BOEING ARE USEFUL TO ILLUSTRATE THE SOURCE OF WEIGHT REDUCTIONS WITH SUBSTITUTION OF COMPOSITES. IN THE NEXT SLIDE (FIGURE 12) IS SHOWN THE REDUCTION IN NUMBER OF ACTUAL PARTS AND IN NUMBER OF FASTENERS WHICH ACCOMPANY PARTS CONSOLIDATION FOR 727, 737 AND 747 COMPONENTS. THE NUMBER OF PARTS IS REDUCED BY 40 TO 55% WITH THE CORRESPONDING ELIMINATION OF APPROXIMATELY 60% OF THE FASTENERS AND TOTAL COMPONENT WEIGHT REDUCTIONS OF 23 TO 26%. THESE FIGURES TYPIFY THE WEIGHT SAVINGS AND THEIR ORIGINS WHICH HAVE BEEN ACHIEVED IN THE NASA-ACEE PROGRAM.

THE NEXT TWO SLIDES ILLUSTRATE THE PROJECTED EXPANSION OF STRUCTURAL COMPOSITES UTILIZATION ON COMMERCIAL AIRCRAFT. FIRST, IN THE NEXT SLIDE (FIGURE 13) ARE SHOWN THE MATERIALS PLANNED TO BE USED ON THE 757 AND 767 SHIPS. FOR REFERENCE PURPOSES, THE 747 CONTAINS APPROXIMATELY 1% FIBERGLASS COMPOSITE WHILE THE 757 AND 767 SHOW 3% COMPOSITE STRUCTURES OF WHICH 2.5% ARE CARBON FIBER AND/OR KEVLAR REINFORCED MATERIAL. WHILE MOST OF THE CURRENT USAGE IS IN SECONDARY STRUCTURES, FAR MORE EXTENSIVE COMPOSITES UTILIZATION IS FORECAST FOR THE 1990'S. THIS IS DEPICTED IN THE NEXT SLIDE (FIGURE 14) WHICH SHOWS 7 TO 32% OF THE STRUCTURAL WEIGHT IN COMPOSITES. HOWEVER, BECAUSE OF THE CONFIDENCE AND RELIABILITY CURRENTLY BEING ESTABLISHED, SEVERAL COMMERCIAL AIRFRAME MANUFACTURERS ARE NOW PROJECTING THAT COMPOSITES WILL

CONSTITUTE MORE THAN 50% OF THE STRUCTURE OF COMMERCIAL TRANSPORTS BY THE EARLY 1990'S.

TO APPRECIATE THE TOTAL POTENTIAL FOR COMPOSITES IN AIRFRAMES, I'VE USED A SCHEMATIC SUCH AS SHOWN IN THE NEXT SLIDE (FIGURE 15). HERE THE STEADY, BUT INCREMENTAL, INCREASES IN SPECIFIC STRENGTH OF DEVELOPING MATERIALS FROM THE 1930'S FORWARD ARE SHOWN. NEW ALUMINUM ALLOYS AND POWDERED METALS SHOW THE SAME CONTINUED INCREMENTAL INCREASES THROUGH THE YEAR 2000. IT IS ONLY WITH THE INTRODUCTION, DEMONSTRATION AND UTILIZATION OF HIGH PERFORMANCE CARBON FIBER COMPOSITES THAT SIGNIFICANT STEP-CHANGES IN PERFORMANCE CAN BE PROJECTED.

WHILE THE MAJORITY OF THE AIRCRAFT UTILIZATION IS BASED ON COMMERCIAL TRANSPORTS, IT MUST BE RECOGNIZED THAT MILITARY AND CIVILIAN UTILIZATION OF CARBON FIBER COMPOSITES WILL MORE THAN DOUBLE THE USAGE QUANTITIES I'VE DISCUSSED. AS POINTED OUT EARLIER, IN ADDITION TO PERFORMANCE, A DRIVING FORCE FOR COMPOSITE SUBSTITUTION OF METALS IS WEIGHT REDUCTION WITH RESULTING FUEL ECONOMY AND/OR IMPROVED RANGE PROVIDING THE DEPENDENT BENEFITS. WHATEVER THE DRIVING CAUSE FOR WEIGHT REDUCTION VIA MATERIAL SUBSTITUTION, THE POSITIVE EFFECT OF CONSERVATION OF CRITICAL MATERIALS SUCH AS TITANIUM REMAINS THE SAME. THE LOWER THE USAGE OF CRITICAL METALS, THE LESS CONSTRAINED IS THE SUPPLY OF SUCH METALS FOR THE CRITICAL APPLICATIONS WHERE SUBSTITUTION IS NOT A VIABLE ALTERNATIVE.

THE AUTOMOTIVE/INDUSTRIAL MARKET, AS SHOWN ON THE NEXT SLIDE (FIGURE 16), IS THE NEXT TARGET FOR STRUCTURAL COMPOSITE MATERIALS. THOUGH MANY DEMONSTRATION ARTICLES HAVE BEEN BUILT OVER THE PAST FEW YEARS, VERY FEW HAVE REACHED EVEN THE LIMITED PRODUCTION PHASE. BY THE WAY, THIS DOES NOT INCLUDE THE CHOPPED GLASS-POLYESTER SHEET MOLDING COMPOUNDS WHICH HAVE FOUND WIDE USAGE AS ZINC REPLACEMENT IN NON-STRUCTURAL APPLICATIONS SUCH AS AUTO GRILL OPENING PANELS AND HEADLAMP COVERS. CHEVROLET IS NOW USING A GLASS EPOXY LEAF SPRING IN STRUCTURAL USAGE IN THE 1981 CORVETTE. NOTE THAT THE SPRING STEEL IT REPLACES CONTAINS SMALL QUANTITIES OF CHROMIUM, ONE OF THE CRITICAL METALS. CONTINUING WITH AUTOMOTIVE APPLICATIONS, THOUSANDS OF COMPOSITE DRIVESHAFTS HAVE BEEN PROTOTYPED FOR TEST AND EVALUATION AT ALL MAJOR AUTOMOTIVE COMPANIES, AND WITHIN A FEW YEARS, SUBSTANTIAL PRODUCTION QUANTITIES ARE EXPECTED. LONGER TERM, METAL MATRIX COMPOSITES ARE CANDIDATES FOR HIGH TEMPERATURE ENGINE COMPONENTS.

IN REVIEWING NON-AUTOMOTIVE AREAS, THE CHEMICAL INDUSTRY UTILIZES SUBSTANTIAL QUANTITIES OF STAINLESS STEEL IN PIPING AND VALVES BECAUSE OF THE CORROSION PROBLEMS WITH ORDINARY STEELS AND COMPOSITE REPLACEMENT POSSIBILITIES ARE BEING ACTIVELY EVALUATED IN THIS INDUSTRY. FOR INSTANCE, THERE'S NOW A COMMERCIALLY AVAILABLE BALL VALVE MADE FROM CHOPPED CARBON FIBER AND PPS (POLYPHENYLENE SULFIDE), A HIGH TEMPERATURE THERMOPLASTIC.

THE MARINE INDUSTRY IS YET ANOTHER AREA WHERE COMPOSITE MATERIALS REPLACEMENT IS OCCURRING, IN THIS CASE, FOR STAINLESS STEELS THAT ARE RESISTANT TO SALT WATER CORROSION. HERE, COMPOSITES THAT CONTAIN GLASS, CARBON, AND KEVLAR FIBERS ARE FINDING INCREASED USAGE IN TUBING, FITTINGS AND TORQUE SHAFTS.

IT'S IMPORTANT TO RECOGNIZE THAT THOUGH THE COMPOSITES ACTIVITY IN THESE INDUSTRIES IS NOT GREAT AT PRESENT, THERE IS CONSTANT ECONOMIC PRESSURE THAT WILL STIMULATE MATERIALS INNOVATION, AND, IN YEARS TO COME, SUBSTANTIAL METAL REPLACEMENT WILL TAKE PLACE.

IN SUMMARY, I'D LIKE TO POINT OUT THAT TWO METHODS FOR ALLE-VIATING THE DEMAND ON CRITICAL METALS BY COMPOSITE SUBSTITUTION HAVE BEEN IDENTIFIED. THE FIRST APPROACH IS THE DIRECT SUBSTITU-TION OF METAL MATRIX COMPOSITES FOR METALS IN HOT ENVIRONMENTS; THIS PERMITS REDUCTION IN THE USAGE OF CRITICAL METALS SUCH AS TITANIUM AND BERYLLIUM. IN THE SECOND APPROACH, THE STRUCTURAL WEIGHT OF A TRANSPORT VEHICLE, SUCH AS AN AIRFRAME, IS DIRECTLY REDUCED BY SUBSTITUTION OF ORGANIC MATRIX COMPOSITES FOR ALUMINUM, AND, ALTHOUGH ALUMINUM ITSELF IS NOT A CRITICAL MATERIAL, A SECONDARY DOWN-SIZING OF THE ENGINE IS NOW PERMITTED AND THIS REDUCES THE QUANTITY OF TITANIUM REQUIRED FRO THE SMALLER ENGINE. SPECIFIC ILLUSTRATIONS OF SUCH COMPOSITE SUB-STITUTION FOR METALS IN BOTH AEROSPACE AND NON-AEROSPACE APPLICATIONS WILL BE GIVEN BY THE TWO SPEAKERS WHO FOLLOW ME THIS MORNING.

FIGURE 1

Structural Composites

Definition:

- Products which utilize very high strength/stiffness fiber reinforcements in combination with conventional polymers or metals to form structural materials with unique property to weight characteristics
- Contain high percentages of fiber reinforcement: 50 - 70% by weight

FIGURE 2

Composites Use: Reasons To Be

- Unique performance characteristics
- Design flexibility/simplification
- Demonstrated cost effectiveness in aerospace/aircraft applications
- Potential for satisfying unique needs in industrial/automotive markets

FIGURE 3

Comparative Specific Composite Properties

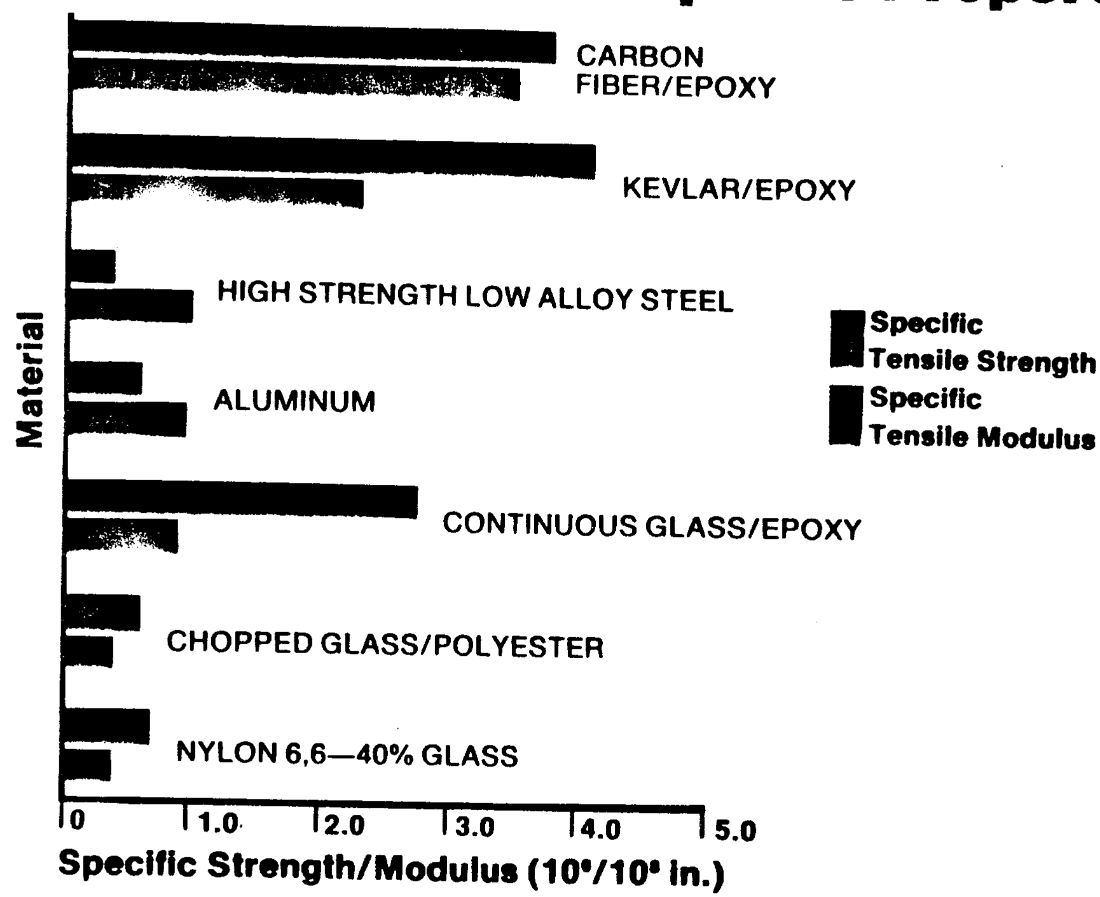


FIGURE 4

Performance Factors Impacting Use Of Carbon Fiber Composites

Advantages

- Low Weight
- High Strength and Stiffness
- Fatigue Resistance
- Vibration Damping Characteristics
- Corrosion Resistance
- Friction and Wear Characteristics
- Low Thermal Expansion
- Electrical Conductivity

Issues

- Impact
- Durability
- Repairability
- Recycling
- Hazards

FIGURE 5

Composite Materials

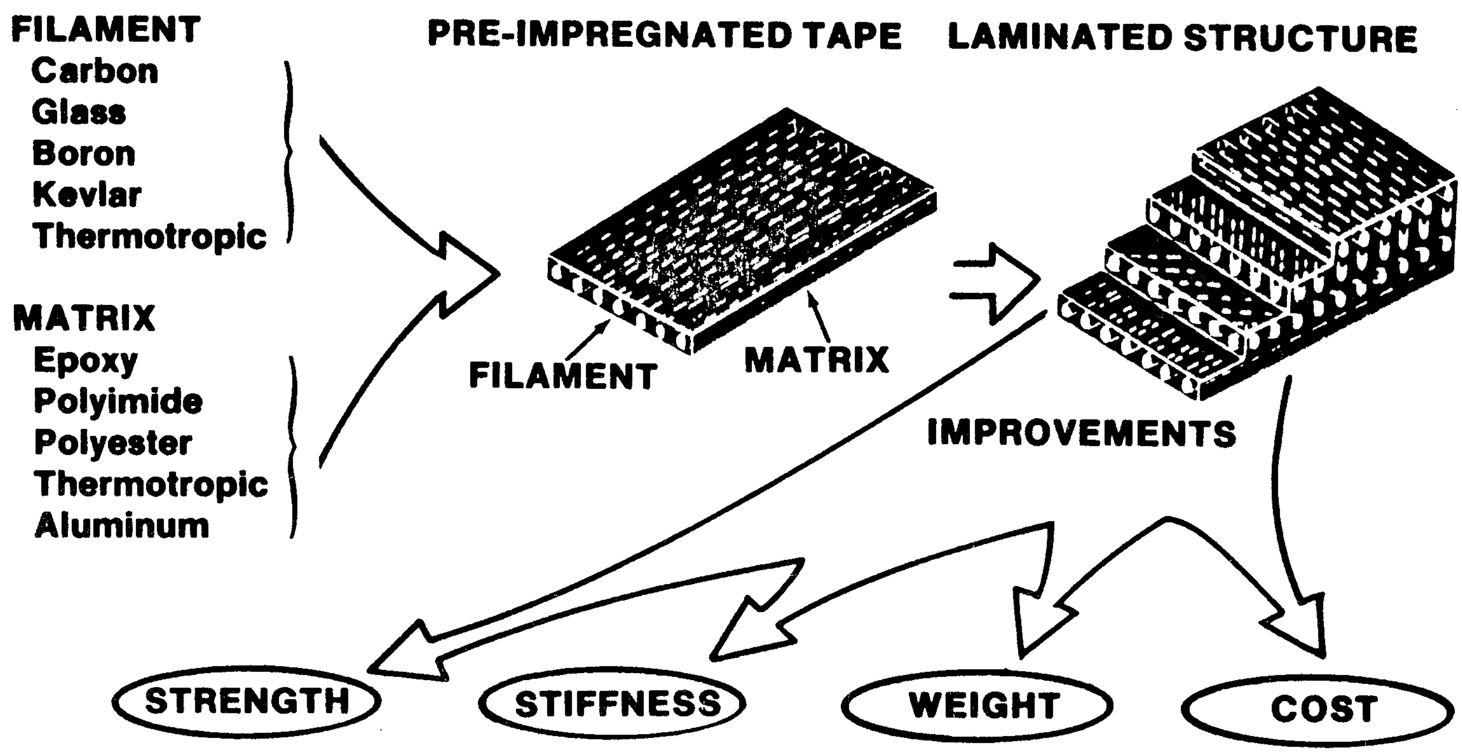


FIGURE 6

Structural Composites: Industry Characterization

- $5MMM metals substitution potential
- Diversified end-use structure
  - —Aircraft/Aerospace
  - —Recreational Products
  - —Industrial Applications
  - —Automotive Uses
- High Technology: large potential for technical innovation in both cost and performance
- High value added potential
- High capital intensity

SCHEMATIC OF FIBER/METAL MATRIX SYSTEMS
CURRENTLY BEING DEVELOPED

FIBER \ MATRIX	Al	Mg	Cu	Ti	Pb
C	X	X	X		
B	X				
SiC	X	X		X	
W					
FP	X	X			

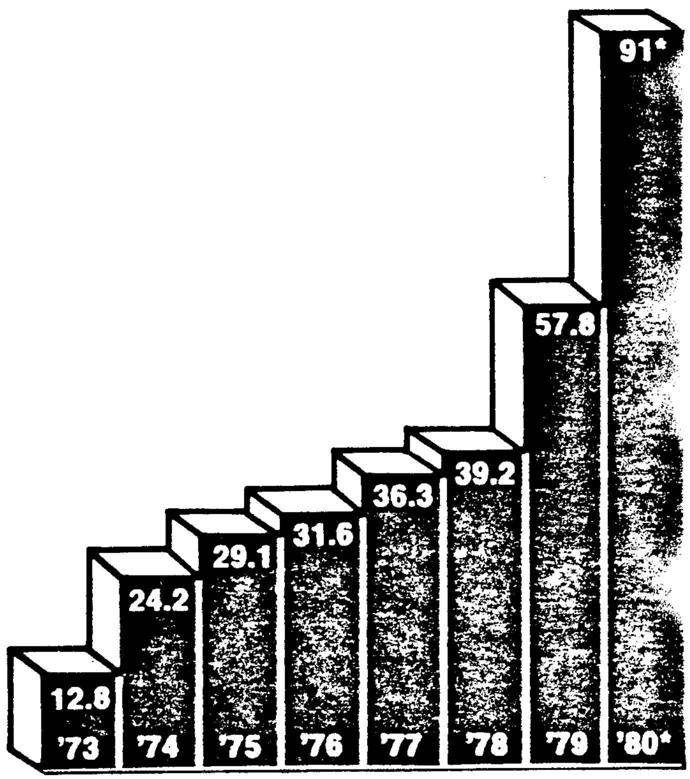
FIGURE 8

Technical and Economic Impact Of Advanced Composites In Aircraft

- Major weight savings
- Major fuel savings
- Major cost reductions
- Demonstrated material performance, reliability, predictability
- High confidence in carbon fiber composites developed

Average Fuel Prices Paid By Airlines

(in cents per gallon)



Source Air Transport Assn *Estimated

FIGURE 10

Impact Of Composites Use On Weight And Cost Savings

(NASA)

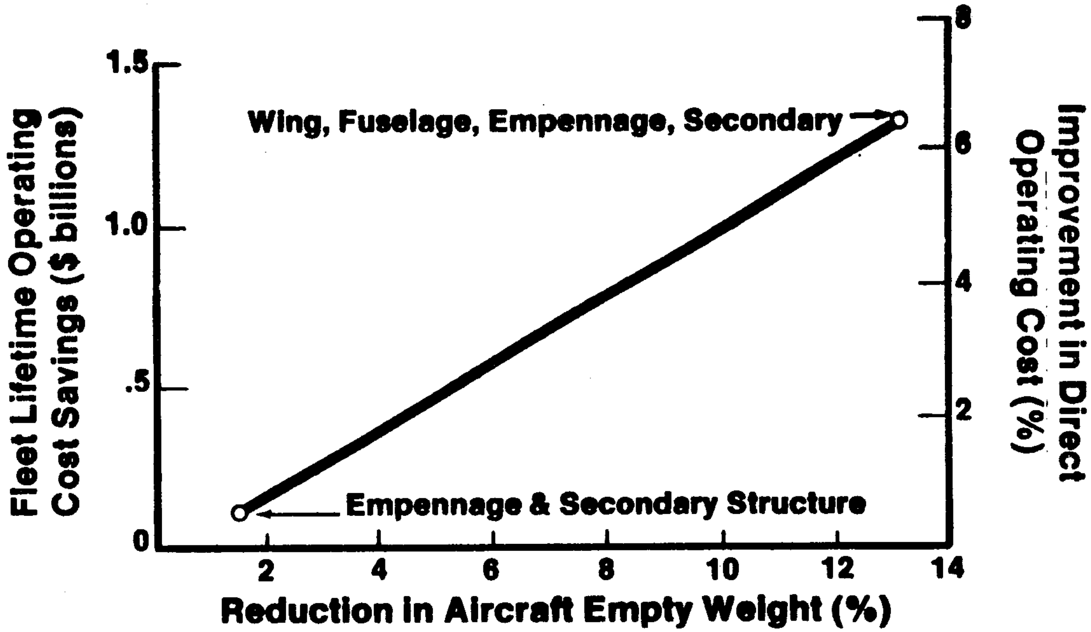


FIGURE 11

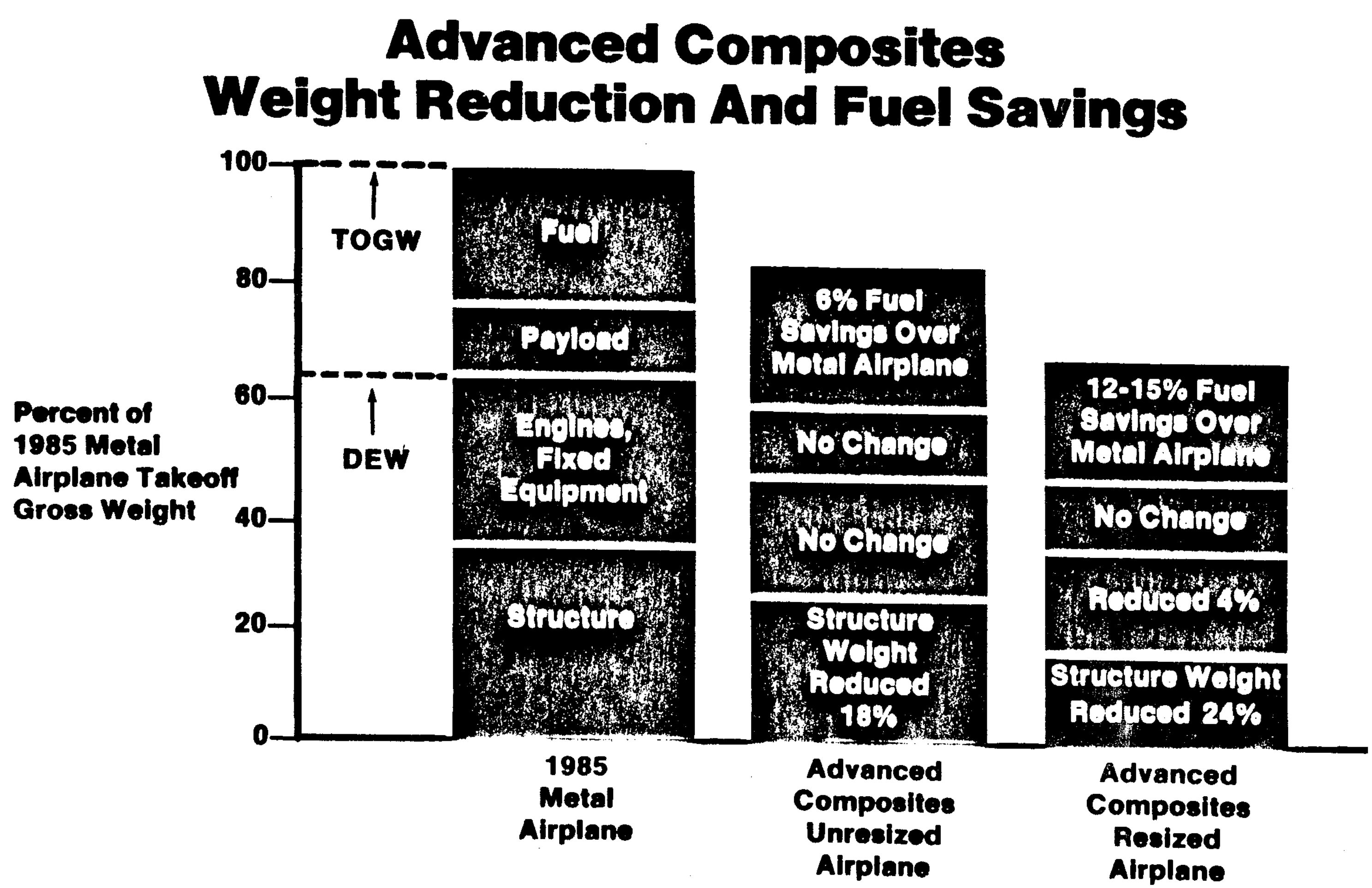

Advanced Composites
Weight Reduction And Fuel Savings
Percent of 1985 Metal Airplane Takeoff Gross Weight
100
80
60
40
20
0
TOGW
DEW
Fuel
Payload
Engines, Fixed Equipment
Structure
6% Fuel Savings Over Metal Airplane
No Change
No Change
Structure Weight Reduced 18%
12-15% Fuel Savings Over Metal Airplane
No Change
Reduced 4%
Structure Weight Reduced 24%
1985 Metal Airplane
Advanced Composites Unresized Airplane
Advanced Composites Resized Airplane

FIGURE 12

Competitive Materials
Advanced Composite Advantages

Component	Reduction		
	Parts	Fasteners	Weight
727 Elevator	40%	approx 60%	26%
737 Stabilizer	55%		23%
747 Aileron	47%		23%

FIGURE 13

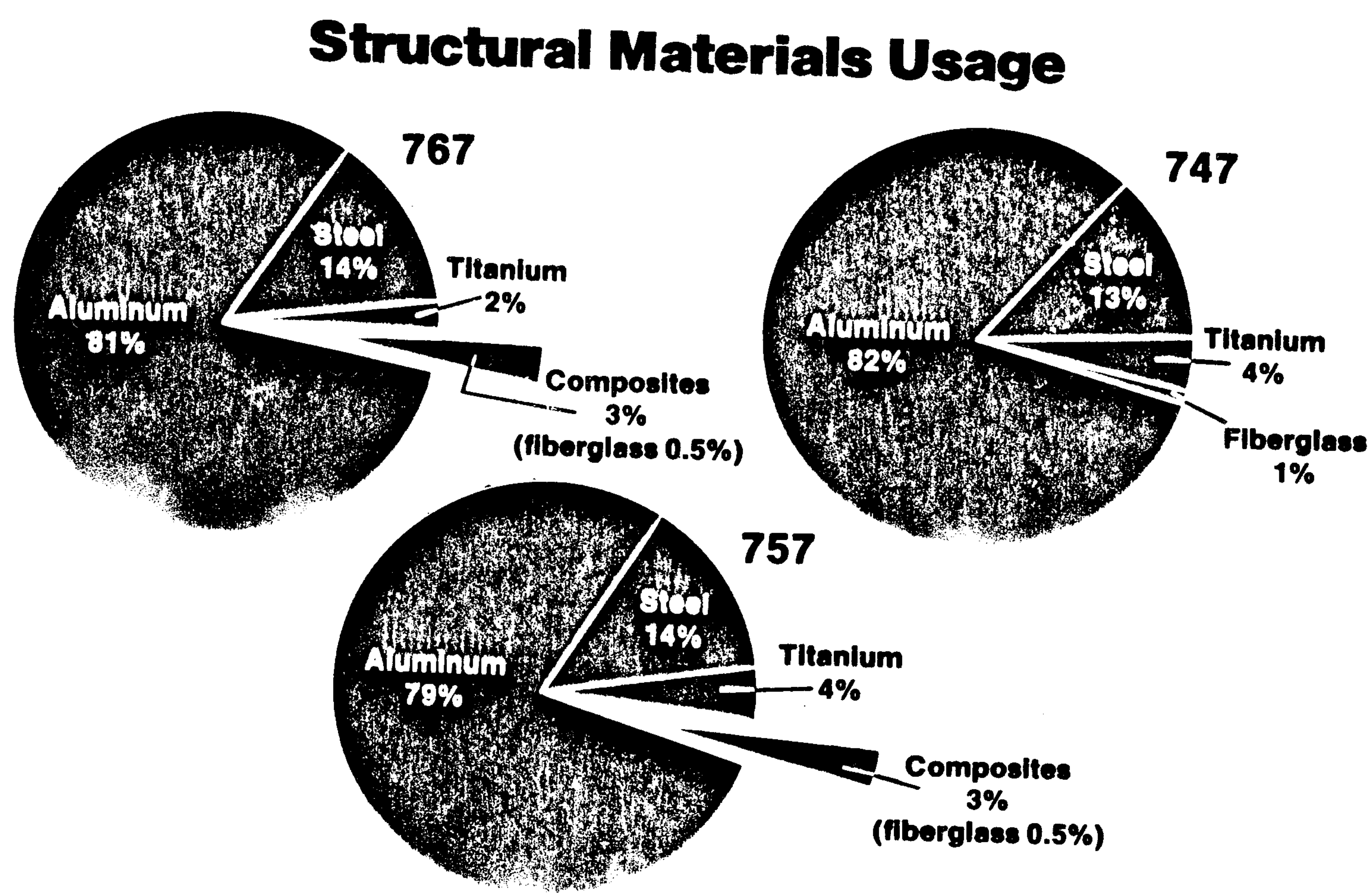

Structural Materials Usage
767
Steel
14%
Titanium
2%
Aluminum
81%
Composites
3%
(fiberglass 0.5%)
747
Steel
13%
Titanium
4%
Aluminum
82%
Fiberglass
1%
757
Steel
14%
Titanium
4%
Aluminum
79%
Composites
3%
(fiberglass 0.5%)

FIGURE 14

Competitive Materials
Structural Material Systems
1990-2000 Era Subsonic Airplane

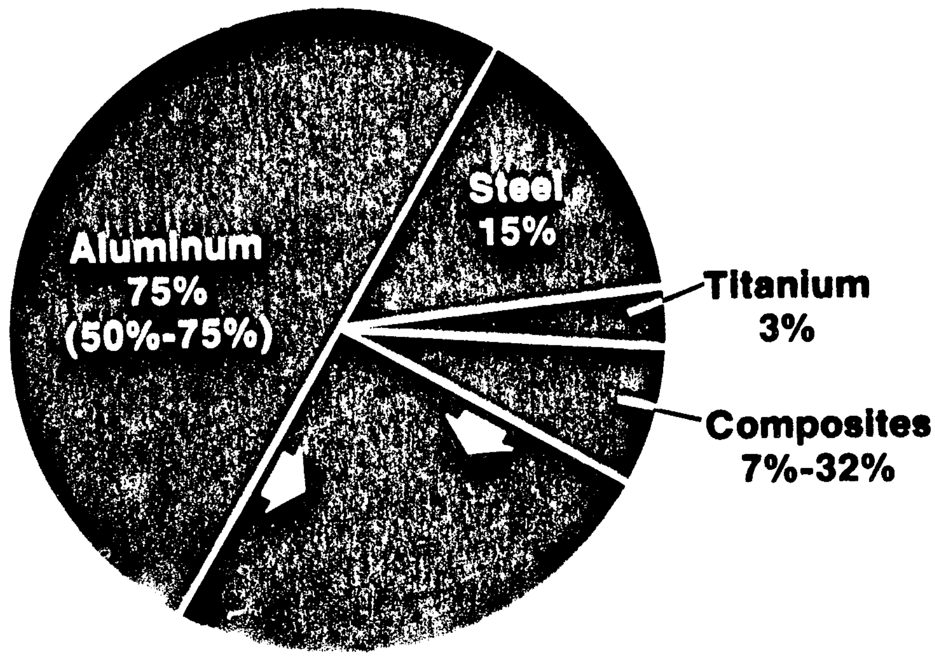


FIGURE 15

Competitive Materials Structural Materials Trends— Commercial Aircraft

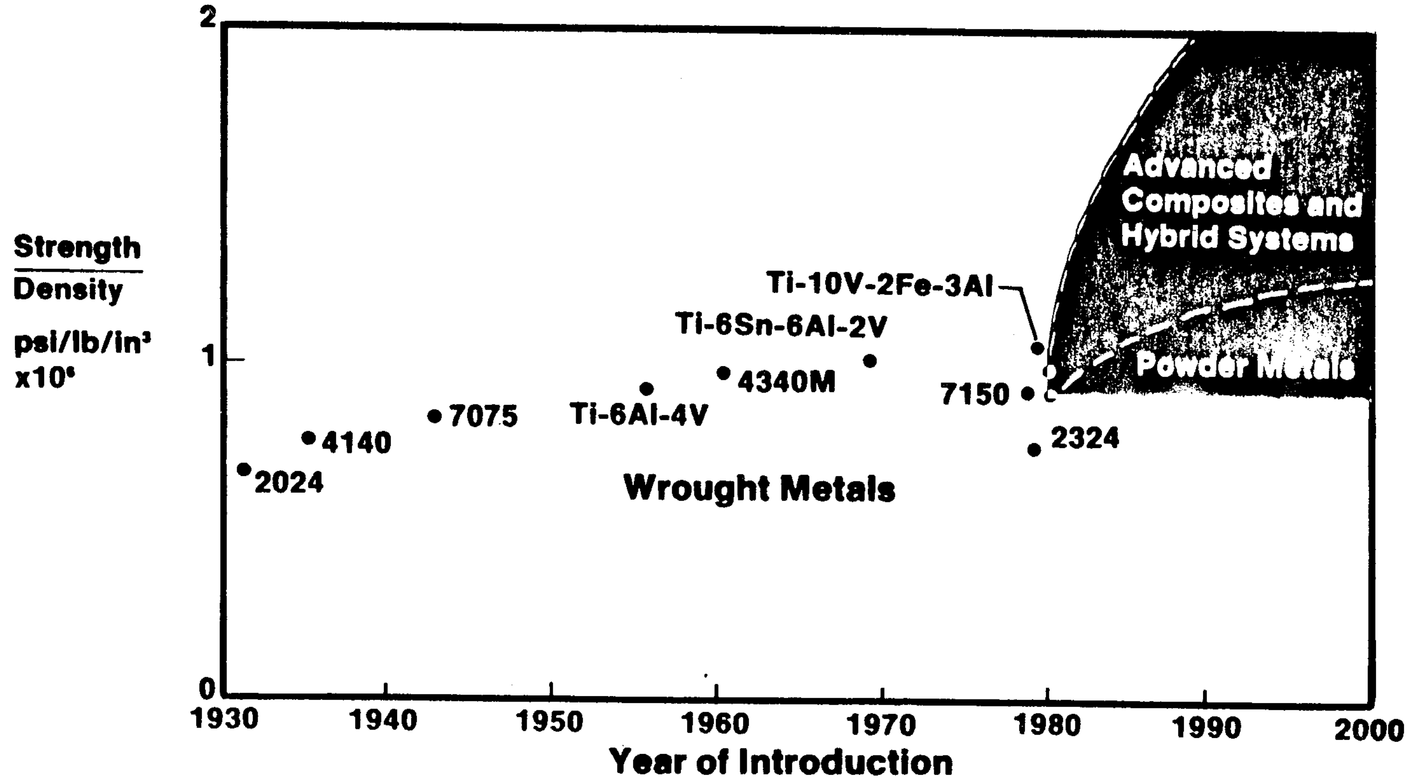


FIGURE 16

AUTOMOTIVE - INDUSTRIAL DEVELOPMENTS

AUTOMOTIVE

Leaf Springs

Driveshafts

Non-Structural Facia's

INDUSTRIAL

Ball Valve

Piping

MARINE

Driveshafts

Fittings

Tubing

ROLE OF COMPOSITES IN SUBSTITUTION, CONSERVATION AND DISPLACEMENT OF MATERIALS AND POTENTIAL FOR SUBSTITUTION IN MILITARY AND COMMERCIAL AEROSPACE

Richard N. Hadcock
Grumman Aerospace Corp.

WORKSHOP ON CONSERVATION AND
SUBSTITUTION TECHNOLOGY FOR CRITICAL MATERIALS

VANDERBILT UNIVERSITY
NASHVILLE, TENNESSEE
15-17 JUNE 1981

SPONSORED BY
U.S. DEPT OF COMMERCE/NATIONAL BUREAU OF STANDARDS
U.S. DEPT OF INTERIOR/BUREAU OF MINES

ROLE OF COMPOSITES IN SUBSTITUTION, CONSERVATION, AND DISPLACEMENT OF MATERIALS AND POTENTIAL FOR SUBSTITUTION IN MILITARY AND COMMERCIAL AEROSPACE

RICHARD N. HADCOCK
GRUMMAN AEROSPACE CORPORATION

GRUMMAN

The Role of Composites in Substitution and Potential for Substitution in Military and Commercial Aerospace*

R. N. Hadcock
Grumman Aerospace Corporation, Bethpage, N.Y.

Abstract

This paper discusses aerospace structural materials, the development of structural composite materials technology, and their properties and current and future applications. Metallic and composite material prices, energy requirements, and availability are addressed. The difference between metal and composite part fabrication is described. In conclusion, an assessment is made of the potential for material substitution.

I. Introduction

Advanced composites structures and materials technologies have been developing steadily during the past 20 years. The technology has reached a level of maturity which led to its use on stabilizers for all new U.S. fighter aircraft since 1970 (F-14, F-15, F-16, YF-17, F-18), and these parts are generally giving trouble-free service. Fighter wing covers (F-18) and the covers and substructure of a V/STOL attack aircraft (AV-8B) are currently being made from graphite/epoxy advanced composite material; these will be entering service in the next year or so. The next generation of commercial aircraft (Boeing 757 and 767) will extensively use advanced composites for such secondary structural parts as ailerons, elevators, rudders, and spoilers. There is still a need for additional development work on high-temperature composite systems, manufacturing technology, the design-manufacturing interface, and fatigue and fracture. However, the technology's current level of maturity makes it a strong candidate for a large proportion of the airframes of future military and commercial aircraft.

II. Material Application

Since new structures and material development takes from 20 to 30 years from conception to widespread application, it is highly improbable that any technologies other than those either currently available or in the advanced development cycle will be sufficiently mature to be considered for application in the next generation of military or commercial aircraft.

Since the beginning of the century, many different materials and types of construction have been used for airframes. Wilbur and Orville Wright used wood, wire, and fabric for their Flyer in 1903. This was the standard type of construction until the middle 1920's, when metal framing began to replace wood. Aluminum stressed-skin had become an accepted form of construction by the early thirties, about 20 years after the first flight of Hans Reissner's all-metal monoplane in 1912. Magnesium airframes came and went (primarily because of major corrosion problems) during the thirties and forties, as did stainless steel (primarily because of weight and manufacturing problems) during the forties and fifties. Material availability has often driven the design in the past. During WW II, shortages of aluminum led to the all-wood de Havilland Mosquito in Britain. It also led to the use of wooden wings in conjunction with aluminum fuselages for the Messerschmitt Me 163. In their time, both the Mosquito bomber and Me 163 fighter had outstanding performance characteristics.

*Presented at the Workshop on Conservation and Substitution Technology for Critical Materials, sponsored by the National Bureau of Standards of the U.S. Dept. of Commerce and the Bureau of Mines of the U.S. Dept. of Interior on June 15-17, 1981, at Vanderbilt University, Nashville, Tennessee.

Titanium had become an accepted material for high-temperature applications by the middle fifties. Titanium utilization reached a peak during the 1960's with the all-titanium SR-71/YF-12; titanium is still extensively used for the wings and carry-through structure of such aircraft as the F-14 and F-15. New process developments such as superplastic forming in conjunction with diffusion bonding and hot isostatic pressing of titanium powders are probable applications of new titanium technology to future tactical aircraft.

By the late sixties, organic-matrix advanced composites had become sufficiently developed for production of the covers of F-14 horizontal stabilizers. Production applications were extended during the seventies to vertical stabilizers and rudders (F-15, F-16), wing covers (F-18), and, finally, to the complete wing, stabilizer, and part of the forward fuselage (AV-8B).

Metal-matrix composites, in the form of boron/aluminum, Borsic/aluminum, boron carbide-coated boron/titanium, and silicon carbide/titanium are currently being developed and could become effective for limited selective reinforcement or replacement of existing metal airframe structures, but only if their costs can be reduced significantly. Boron/aluminum composites are being used for tubular support struts in the keel of the fuselage of the Space Shuttle. Metal matrix composites are likely to be extensively used for space applications due to their excellent thermal stability properties in combination with high specific stiffness. Aerospace materials application during the twentieth century is depicted in Fig. 1, and the full 25-year advanced composite development cycle is illustrated in Fig. 2.

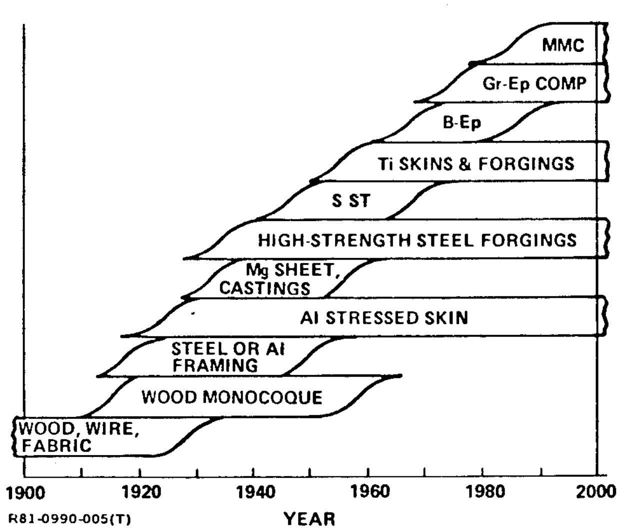


Fig. 1 Aerospace Materials Application

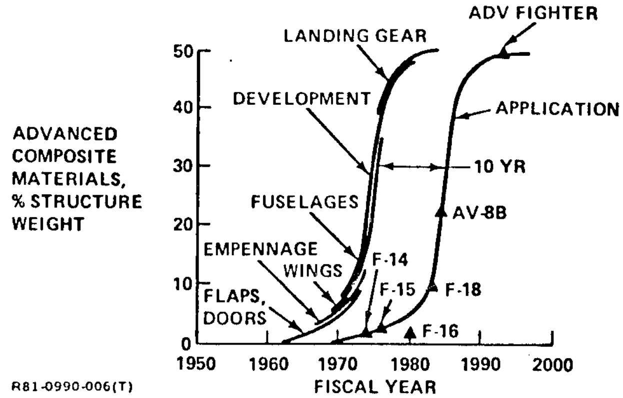


Fig. 2 Advanced Compoiste Implementation (Aircraft)

Figure 3 provides a comparison between advanced composite and metallic specific tensile strengths. Here, the strengths of the composites used are realistic working stress levels for multi-directional laminates as would be used for wing or stabilizer covers. Figure 3 shows that composites

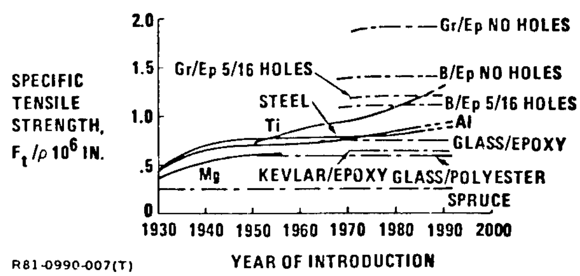


Fig. 3 Specific Working Tensile Strengths of Materials

are very hole-sensitive relative to metals. However, this penalty is offset by far less sensitivity to tension fatigue. Their effectiveness in compression applications is shown in Fig. 4 where the low density

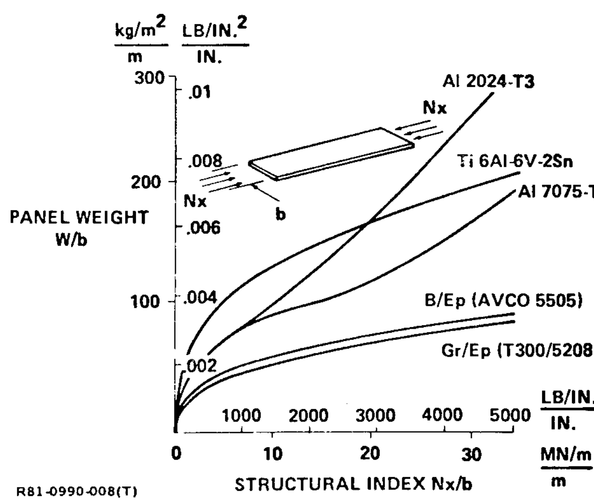
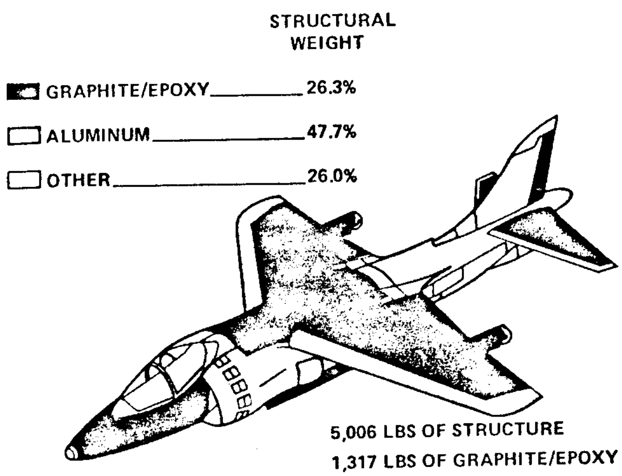


Fig. 4 Weight of Long Compression Panels

significantly reduces panel weight but, in contrast to metals, compression fatigue now becomes a design consideration.

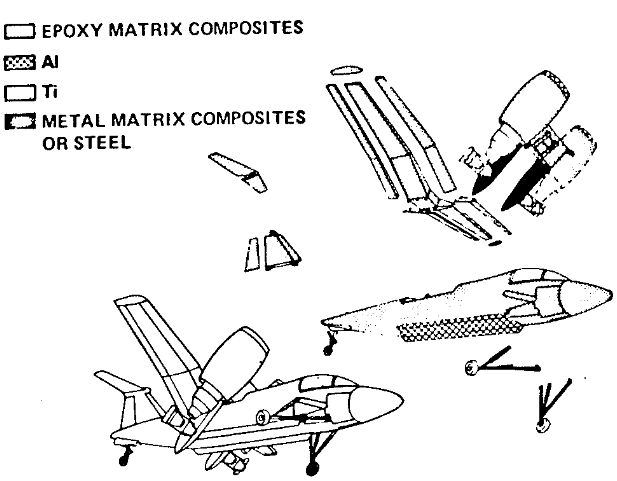
Materials are available or currently under development which could effect significant weight reductions on future aircraft. It is very probable that all future high-performance aircraft, whether military or commercial, will be made from a mix of aluminum, titanium, steels, and advanced composites. The use of advanced composites is expected to increase with time. Figure 5 shows the material mix of AV8B V/STOL aircraft which is just entering production.



R81-0990-009(T)

Fig. 5 AV-8B Composite Application

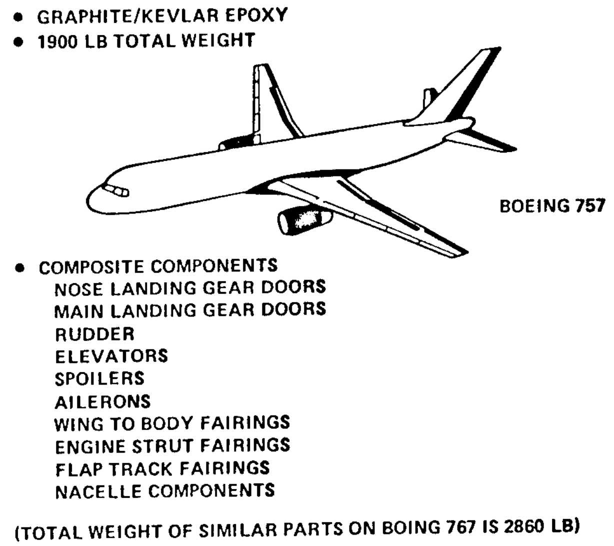
A conceptual subsonic Navy V/STOL aircraft of the 1990's is shown in Fig. 6. Composites would probably account for more than 60% of the weight of this Airborne Early Warning (AEW) aircraft.



R81-0990-010(T)

Fig. 6 Material Distribution - Subsonic V/STOL AEW Aircraft

Composites secondary structure on the new Boeing 757 commercial aircraft is shown in Fig. 7. Total weight is 1900 lb of a mixture of graphite and Kevlar/epoxy. The total weight of composites on the larger Boeing 767 is 2860 lb.

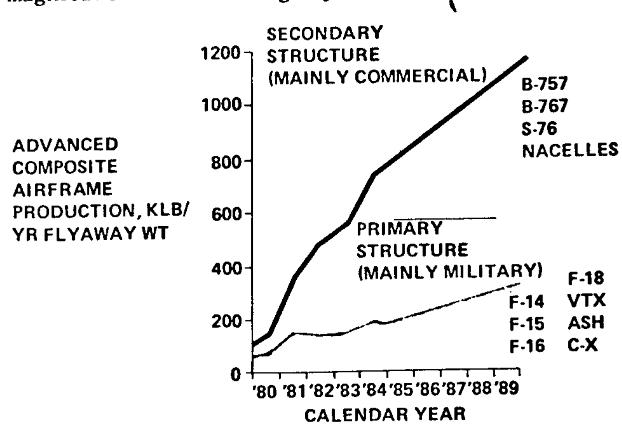


R81-0990-011(T)

Fig. 7 Next Generation Commercial Aircraft Advanced Composite Material Utilization

The use of composites in these aircraft applications will result in lower procurement and operating costs. The weight savings are directly transformed into improved performance and fuel savings or, in the case of military aircraft, into smaller, lighter, and less expensive aircraft capable of the same mission performance.

A projection of the flyaway weight of advanced composite aircraft and helicopter structure is shown in Fig. 8. Composites are projected to account for at least 1 million lb of structure by 1988, an order of magnitude increase in eight years. It can be seen

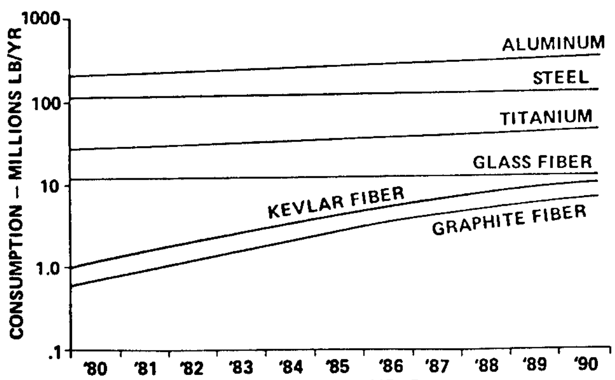


R81-0990-012(T)

Fig. 8 U.S. Advanced Composite Airframe Production 1980-1990 (Commercial & Military Aircraft & Helicopters)

from the figure that only 25% of the material will be used for primary structure, mainly in the form of wing and stabilizer covers of military aircraft. The major use of these materials will be for secondary structure of commercial aircraft.

Total aerospace material consumption estimates to 1990 are shown in Fig. 9. In addition to aluminum, steel, and titanium, consumption estimates are shown for graphite, glass, and Kevlar fiber. It should be noted that the glass and Kevlar fiber composites are and will continue to be utilized for secondary airframe structures and filament-wound rocket motor cases. Boron, silicon carbide, and alumina fibers have not been included in the chart since they are projected to be used only in small quantities. Although the consumption of both graphite and Kevlar fiber is projected to increase by an order of magnitude, the proportion of fiber weight increases only from 8.5% in 1980 to 11% in 1990.



R81-0990-013(T)

Fig. 9 U.S. Aerospace Material Consumption Estimates

Three factors are primarily responsible for inhibiting widespread substitution of composites for metals. These are:

- Material costs
- Manufacturing facilities costs
- Non-recurring costs associated with design, development, tooling, and certification of replacement parts where composites are substituted for metals.

Flyaway costs of primary structural materials are shown in Fig. 10. The graphite/epoxy material has a flyaway cost four times higher than aluminum ($60/lb vs $15/lb). Allowing for weight savings of 25% to 30%, which have been typically demonstrated using graphite/epoxy, material cost of the composite

	MATERIAL	PRICE, $/LB	BUY-TO-FLY RATIO (TYPICAL)	FLY-AWAY COST $/LB
CONVENTIONAL TECHNOLOGY	ALUMINUM	1.80-2.2	8.0	15
	STEEL (PH STAINLESS)	2.70	5.0	14
	TITANIUM	16-31	6.0	100
ADVANCED TECHNOLOGY	GRAPHITE/EPOXY TAPE	38-55	1.3	60
	GRAPHITE/EPOXY CLOTH	70-80	2.0	150
	BORON/EPOXY TAPE	242	1.25	300
	TITANIUM-NEAR NET SHAPES	25-40	1.5	53
	TITANIUM-SPF/DB	16-31	2.0	50
	B/B_4C/TITANIUM	600-1000	1.2*	1000

*WHEN USED AS SELECTIVE REINFORCEMENT

R81-0990-014(T)

Fig. 10 Aerospace Material Prices Fall 1980

part is still effectively twice as high as its aluminum counterpart. This recurring cost difference must be offset by lower manufacturing costs or by lower operating costs if the composite part is to be competitive.

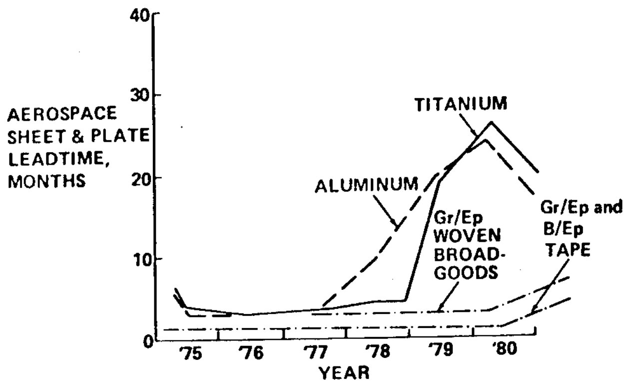
This situation could change if there is again a major escalation in the price of energy. Energy requirements for conventional metals fabrication and advanced composites and titanium fabrication are compared in Fig. 11. As can be seen, the energy associated with composites fabrication is only 15% of that needed for aluminum.

		ENERGY (10^3 BTU/FLYAWAY LB)				
		RAW MATERIAL				
	MATERIAL	BILLET	BUY-TO-FLY RATIO (TYP)	SUBTOTAL	CONVERSION (TYP)	TOTAL
CONVENTIONAL TECHNOLOGY	ALUMINUM	108	8.0	864	64	928
	STEEL	19	5.0	95	260	355
	TITANIUM	185	6.0	1110	258	1368
ADVANCED TECHNOLOGY	COMPOSITES	40	1.5	60	78	138
	TITANIUM-SPF/DB	185	2.0	370	160	430

R81-0990-002(T)

Fig. 11 Energy Requirements

The situation could also change if the 1979 aluminum and titanium sheet, plate, extrusion, and forging lead times of 24 to 35 months recur. Lead time for some graphite/epoxy materials have lately risen from two or three months to twelve months, but this situation is likely to be improved during the coming year. Typical historical data on material lead-times is shown in Fig. 12.



R81-0990-015(T)

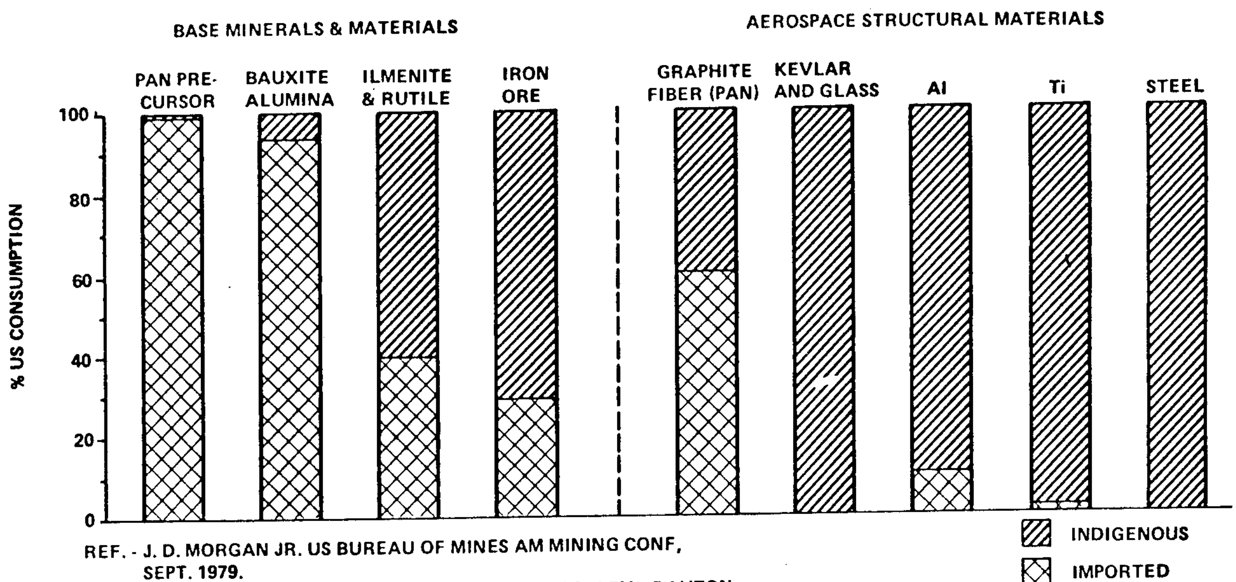
Fig. 12 Aerospace Material Leadtimes - Sheet and Plate

The availability of indigenous sources of both base materials and final material form is of concern. Although Kevlar and glass fiber is 100% available from indigenous sources, the polyacrylonitrile (PAN) precursor, which is used as a base for the structural graphite fiber, is currently 98% imported from Japan and the United Kingdom. In addition, almost 55% of the graphite fiber is currently imported from Japan.

The situation will be improved as the new facilities in South Carolina come on line, but it is very likely that imported PAN precursor and fiber will account for the majority of U.S. graphite fiber sources throughout the 1980's. In comparison, almost 90% of aluminum production is indigenous, even though imported Bauxite accounts for 92% of the base mineral (Fig. 13).

III. Manufacturing Considerations

The processes associated with conventional metal and composite part fabrication are totally different. Incoming metal, in the form of sheet, plate, extrusion, or forgings, is inspected and stored in a warehouse. The material is rough cut to size, packaged with operation sheets, machined, formed, trimmed, cleaned, heat treated, and inspected prior to assembly. The parts are then assembled by bolting, riveting, welding, or adhesive bonding to form components. A significant proportion of the material is removed during the machining operations (Fig. 10 shows typical buy-to-fly ratios).

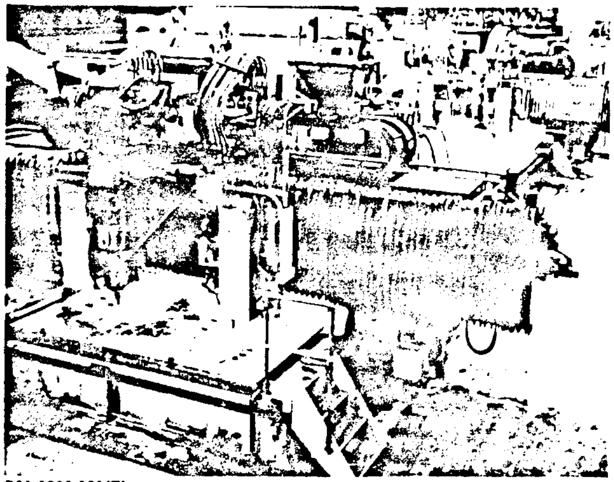


REF. - J. D. MORGAN JR. US BUREAU OF MINES AM MINING CONF, SEPT. 1979.
SEMINAR ON CRITICAL/STRATEGIC MATERIALS, AFML DAYTON FEB. 1979
"AVAILABILITY OF STRATEGIC MATERIALS" AV. WEEK MAY 5, 1980
"DEFENSE SCIENCE BOARD URGES MULTIYEAR CONTRACTS" AV. WEEK DEC 1, 1980

R81-0990-016(T)

Fig. 13 U.S. Aerospace Structural Material Availability (1980) Indigenous/Imported

Typical large, two-spindle, three-axis aluminum skin mills are shown in Fig. 14. More complex shapes are machined using five-axis numerically controlled machines.

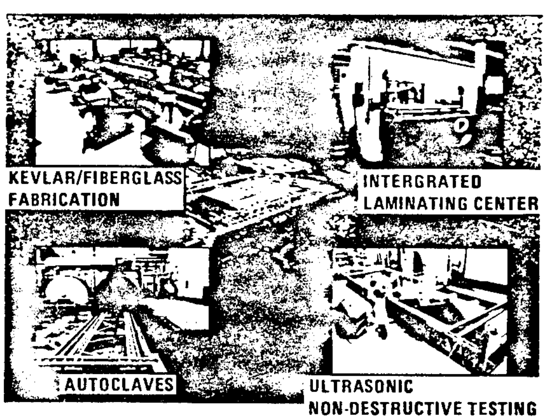


R81-0990-021(T)

Fig. 14 Aluminum Skin Mill

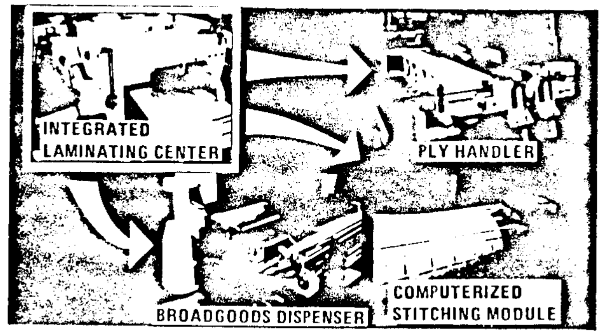
Entirely different processes and facilities are utilized for fabrication of organic matrix composite parts. The structural composite material is received in the form of preimpregnated tape or broadgoods in refrigerated containers. It is then inspected visually and destructive test specimens are fabricated to determine that physical and mechanical properties meet the material specification. The material is stored in a refrigerator since a room temperature environment causes the resin to advance and limits out-time.

Part fabrication consists of trimming individual plies to shape, stacking and debulking the plies on the tool, and finally autoclave curing under a combination of temperature and pressure. The ply trimming and layup (stacking) operations should be performed in a humidity/temperature controlled clean



R81-0990-019(T)

Fig. 15 Milledgeville, Georgia, Composites Facility



- RAPID LAYUP, TRIMMING & INSPECTION
- TAPE & BROADGOODS
- GENTLE CONTOURS
- COMPLEX FUSELAGE SHAPES
- AUTOCLAVE LOADING TIE-IN

R81-0990-020(T)

Fig. 16 Material and Manufacturing Development Automated Integrated Manufacturing System (AIMS) for Advanced Composites

room and accomplished within a specified time period, usually one week. The cured parts are trimmed to final size and inspected. Figure 15 shows the Grumman composite facility. Figure 16 shows elements of an automated integrated manufacturing system for fabrication of complex composite parts which has lately been developed.

IV. Conclusions

Composites will constitute a larger proportion of the airframe weight of future military and commercial aircraft. The resulting weight savings will result in significant reductions in life cycle costs. However, widespread substitution of composites for aluminum and titanium in existing structural parts is unlikely due to the costs of redesign, development, tooling, and certification. Even so, the aerospace utilization of structural composites will increase by at least an order of magnitude by the end of the decade. This will require major investment in new manufacturing facilities dedicated to automated fabrication of complex composite parts.

Bibliography

R. N. Hadcock, "Introduction of New SDM Technology into Production Systems," AIAA paper 79-071R, Journal of Aircraft, Vol. 17, No. 9, September 1980.

R. N. Hadcock, "The Introduction of Advanced Metallic and Composite Structures into Future Tactical Aircraft," Tactical Aircraft Research and Technology Conference, NASA Langley Research Center, Hampton, VA, October 1980. (NASA CP-2162 Vol. II.)

J. D. Morgan, Jr., "Minerals Availability - The Mineral Position of the United States," American Mining Congress Annual Meeting, Los Angeles, CA, September 1979.

"Seminar on Critical/Strategic Metals Status," Air Force Wright Aeronautical Laboratories, Materials Laboratory, Dayton, OH, February 1979.

D. E. Fink, "Technical Survey - Availability of Strategic Materials," Aviation Week and Space Technology, May 5, 1980.

Richard G. O'Lone, "Aeronautical Engineering Industry Tackles Composites Challenge," Aviation Week and Space Technology, September 15, 1980.

WORKSHOP ON THE POTENTIAL ROLE OF ADVANCED MATERIALS IN THE AEROSPACE INDUSTRY

VANDERBILT UNIVERSITY, NASHVILLE, TENNESSEE
JUNE 15-17, 1981

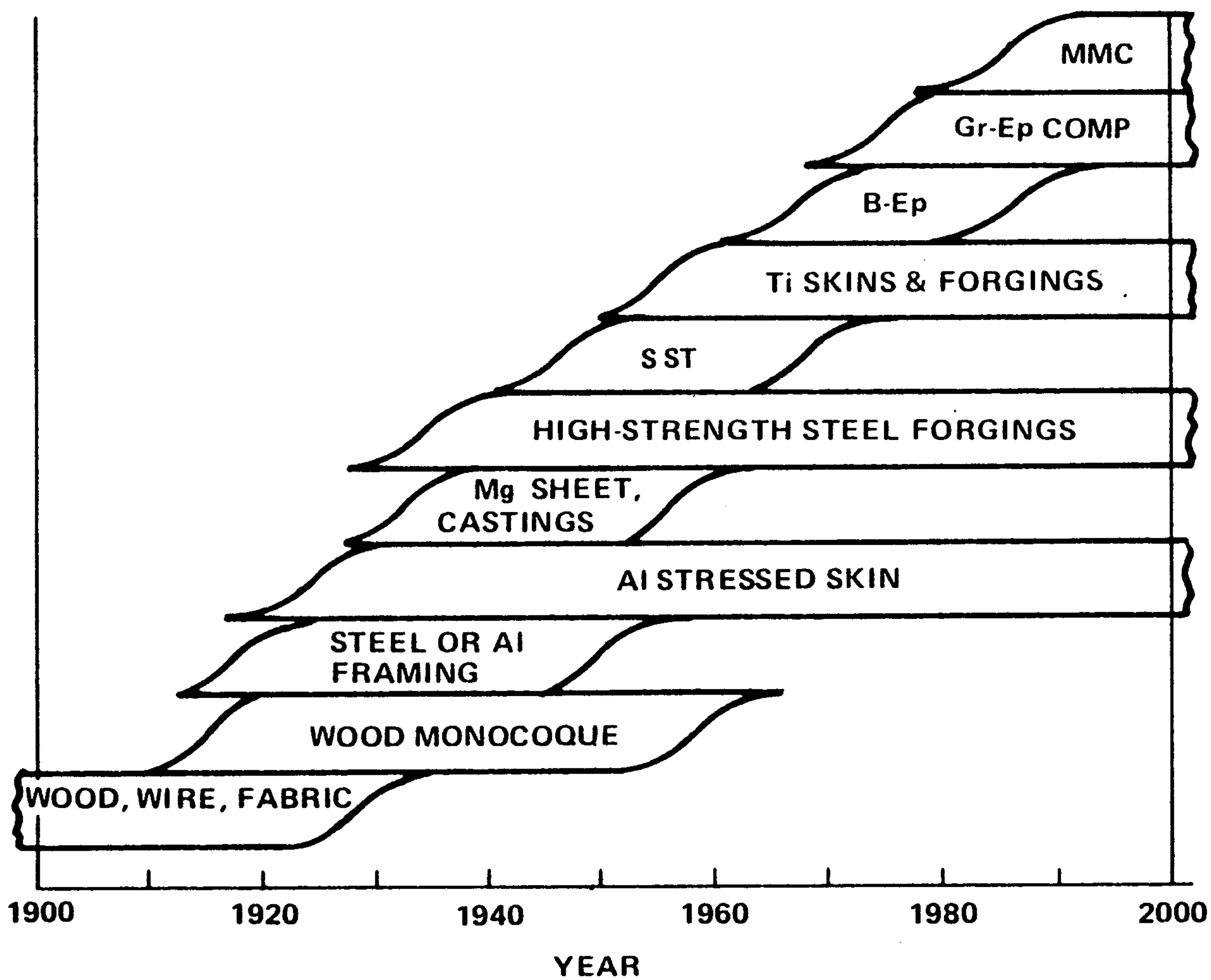
SESSION V

ROLE OF COMPOSITES IN SUBSTITUTION, CONSERVATION, AND DISPLACEMENT OF CRITICAL METALS AND POTENTIAL FOR SUBSTITUTION IN AEROSPACE, MILITARY, AND COMMERCIAL APPLICATIONS

RICHARD N. HADCOCK

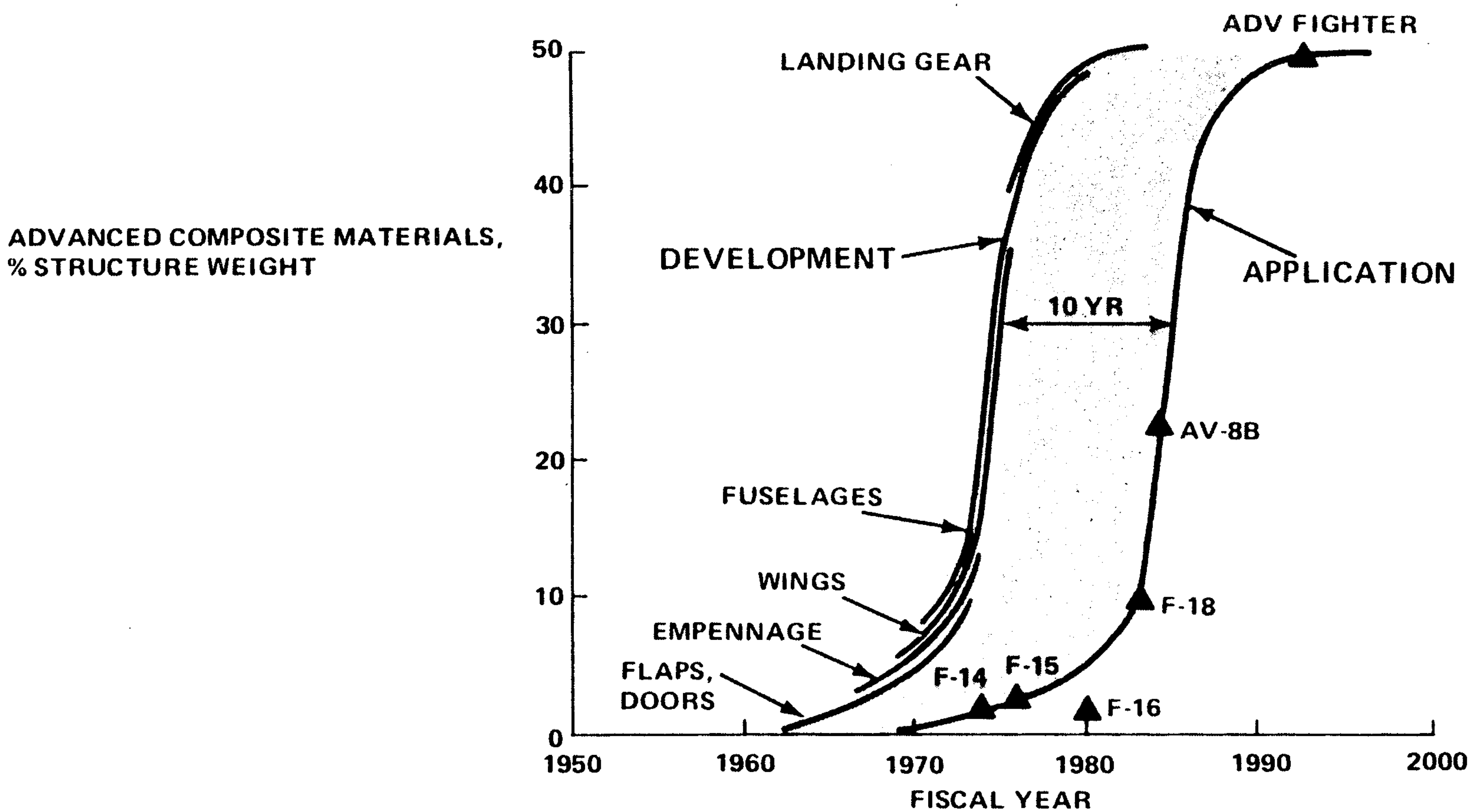
GRUMMAN AEROSPACE CORP

AIRCRAFT MATERIALS APPLICATION



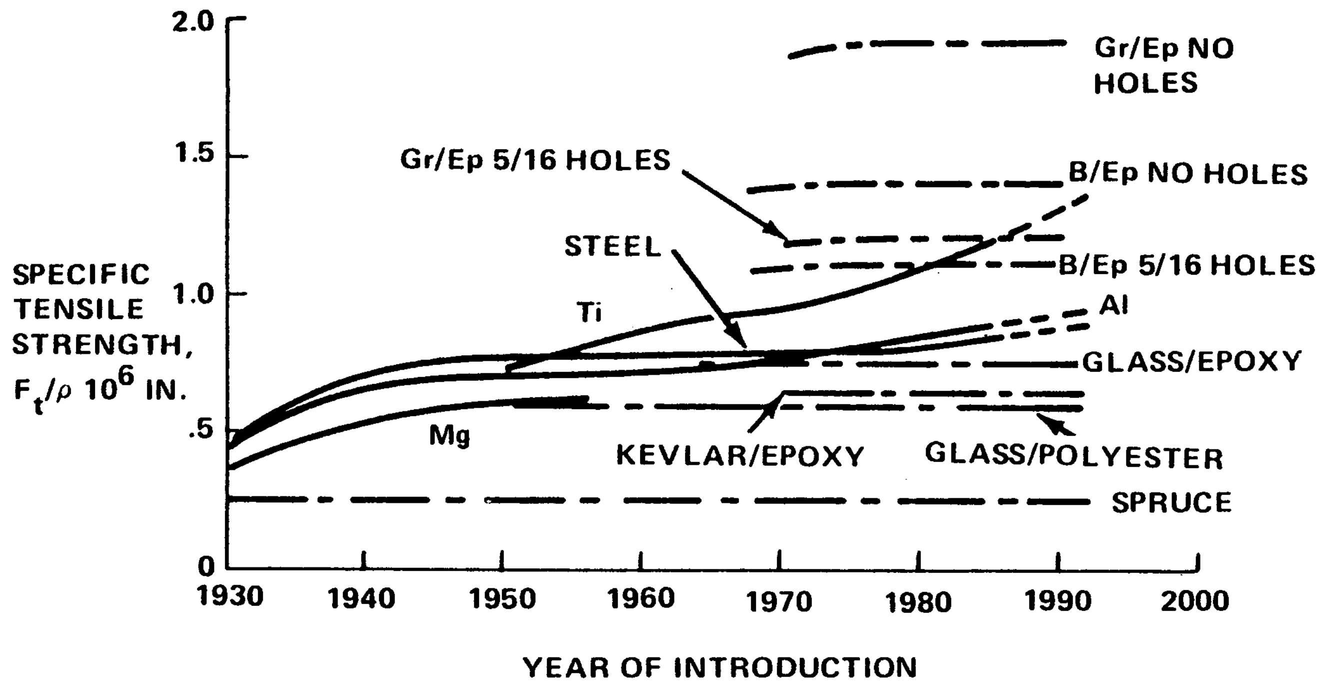
P42-9

ADVANCED COMPOSITE IMPLEMENTATION (AIRCRAFT)

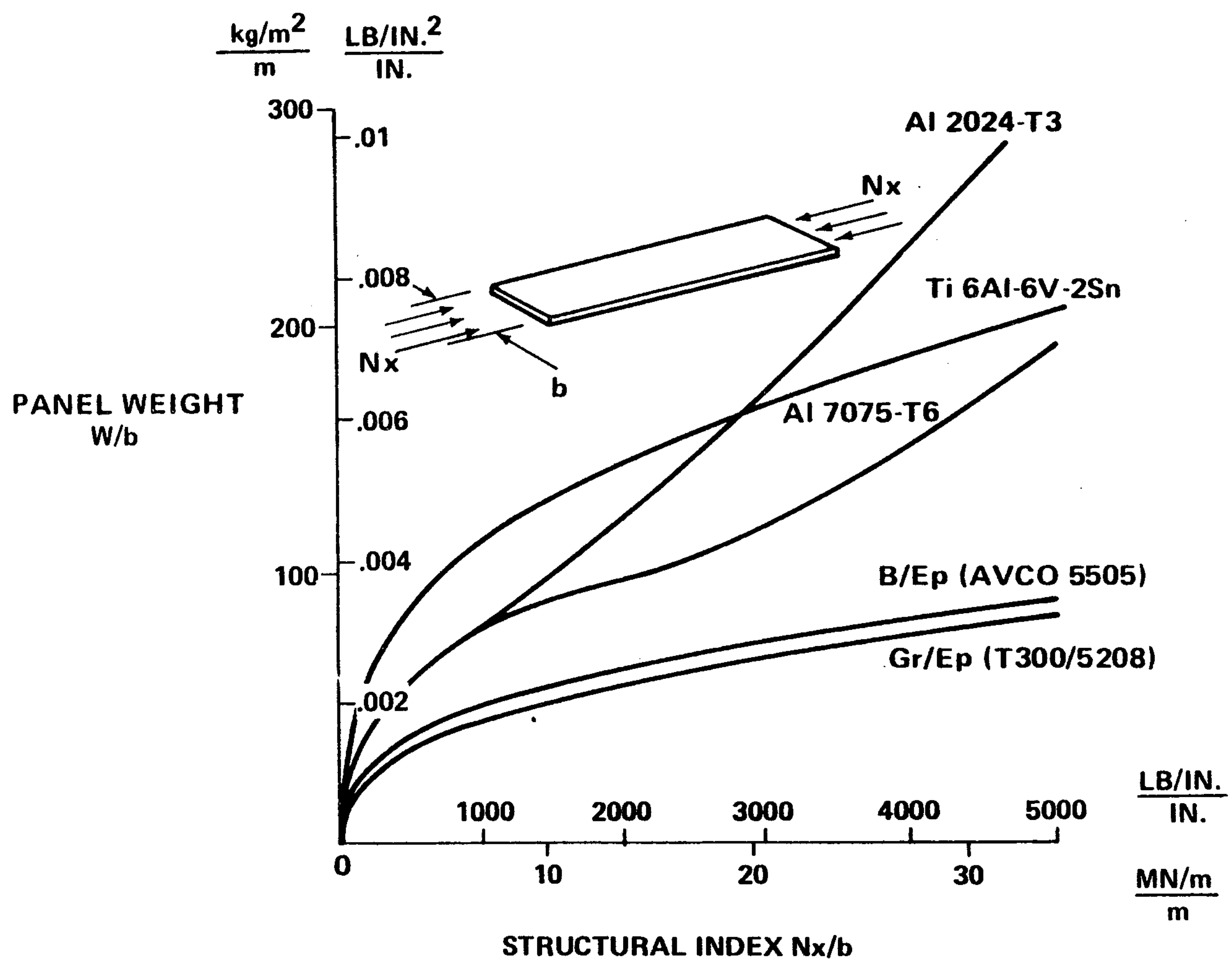


P42-10

SPECIFIC WORKING TENSILE STRENGTHS OF MATERIALS

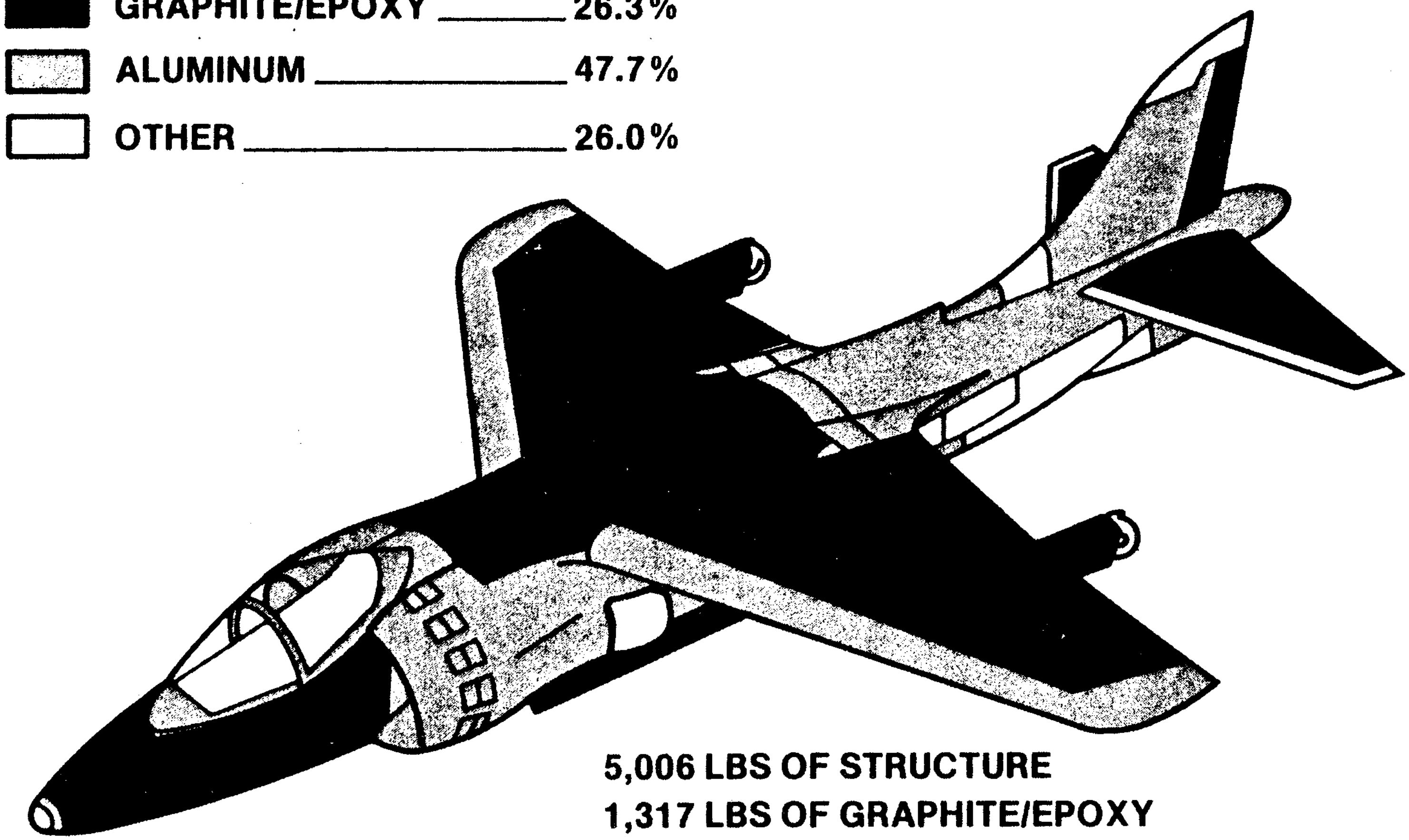


WEIGHT OF LONG COMPRESSION PANELS



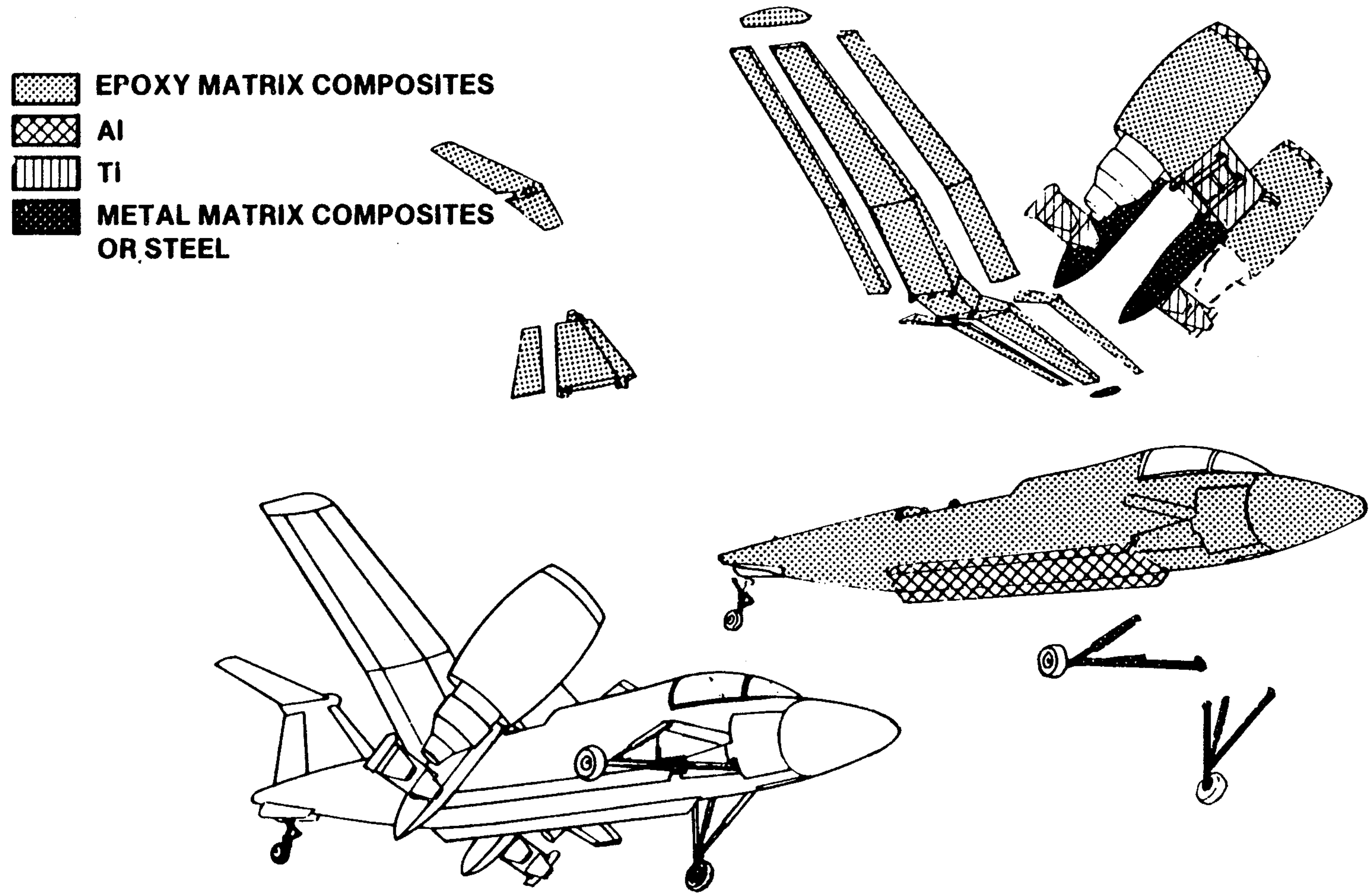
AV-8B COMPOSITE APPLICATION

	STRUCTURAL WEIGHT
GRAPHITE/EPOXY	26.3%
ALUMINUM	47.7%
OTHER	26.0%



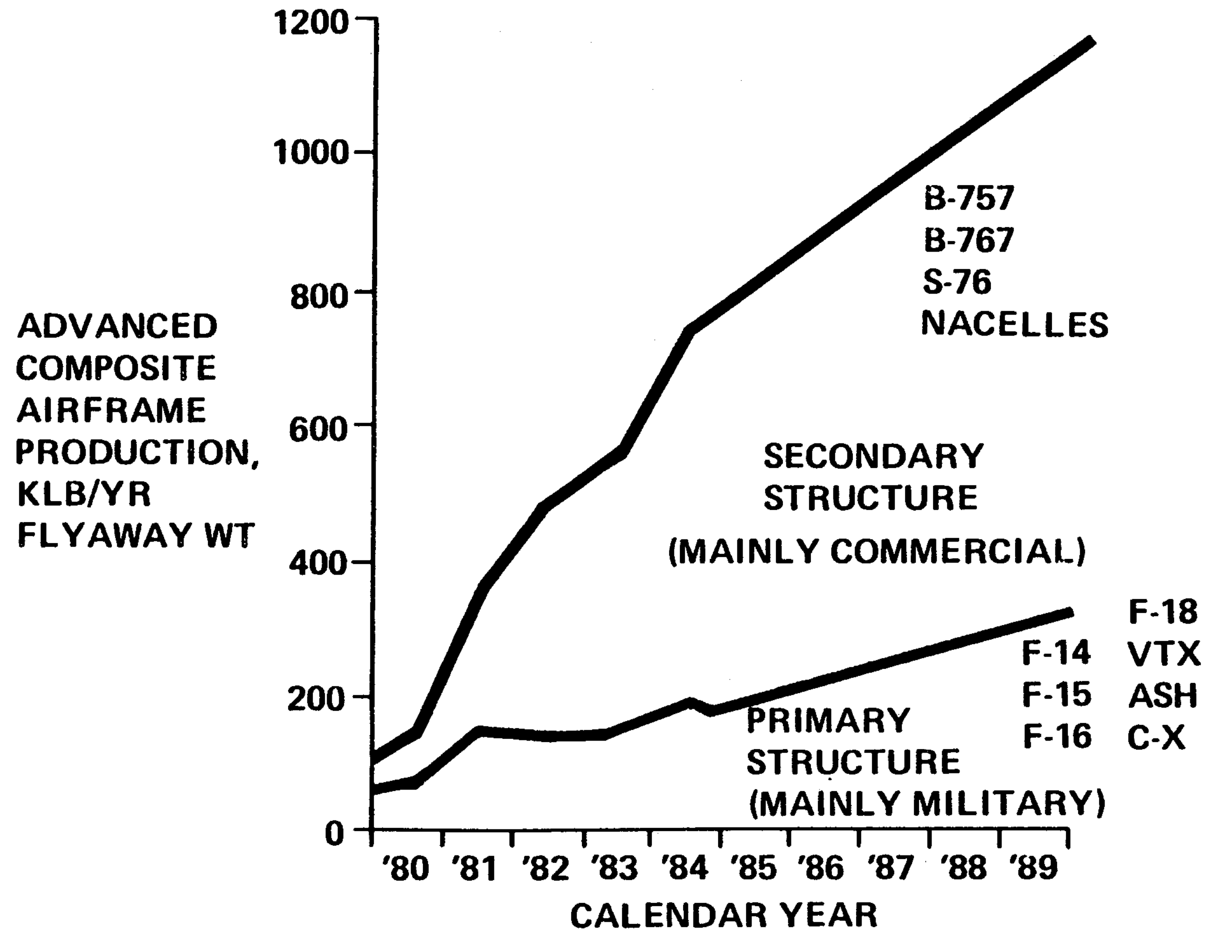
5,006 LBS OF STRUCTURE
1,317 LBS OF GRAPHITE/EPOXY

MATERIAL DISTRIBUTION—SUBSONIC V/STOL AEW AIRCRAFT



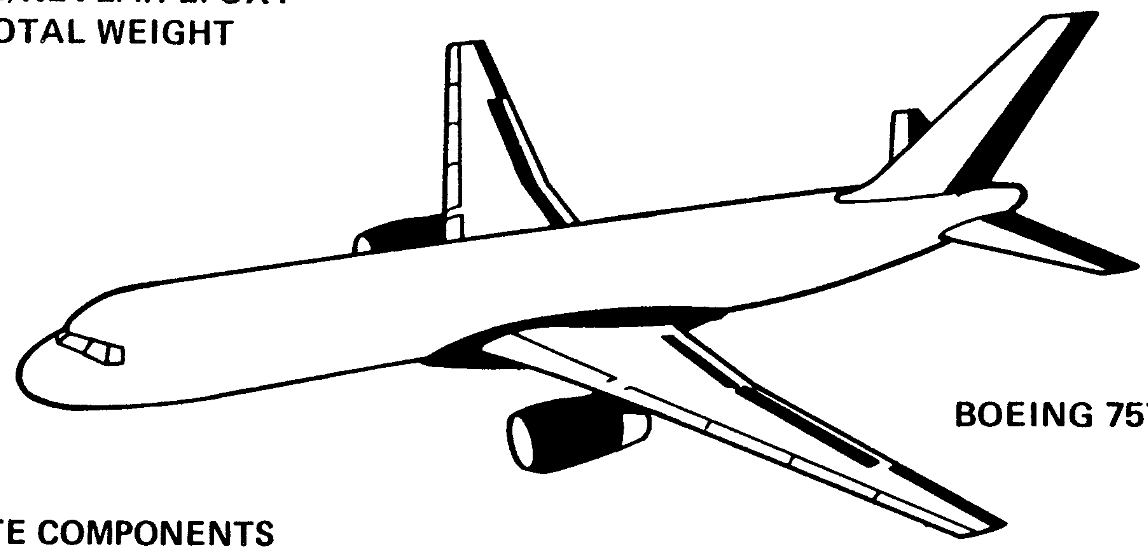
U.S. ADVANCED COMPOSITE AIRFRAME PRODUCTION 1980-1990

(COMMERCIAL & MILITARY AIRCRAFT & HELICOPTERS)



NEXT GENERATION COMMERCIAL AIRCRAFT ADVANCED COMPOSITE MATERIAL UTILIZATION

- GRAPHITE/KEVLAR EPOXY
- 1900 LB TOTAL WEIGHT

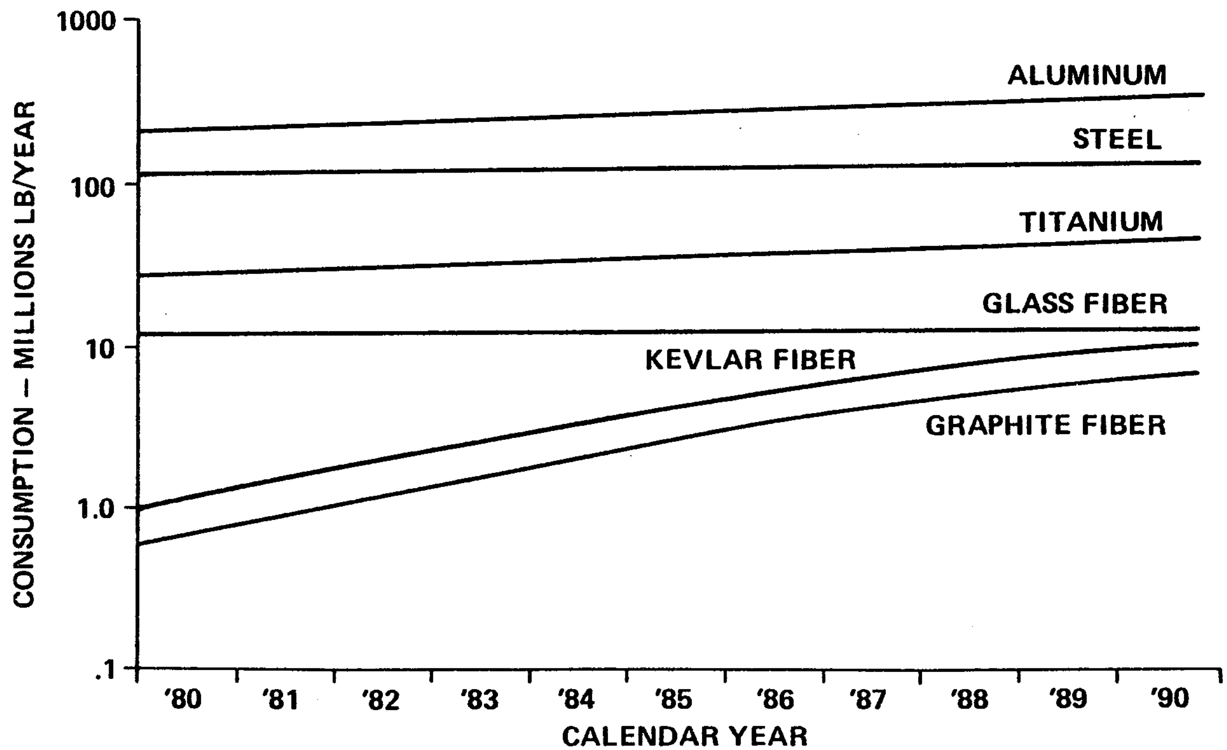


BOEING 757

- COMPOSITE COMPONENTS
  - NOSE LANDING GEAR DOORS
  - MAIN LANDING GEAR DOORS
  - RUDDER
  - ELEVATORS
  - SPOILERS
  - AILERONS
  - WING TO BODY FAIRINGS
  - ENGINE STRUT FAIRINGS
  - FLAP TRACK FAIRINGS
  - NACELLE COMPONENTS

(TOTAL WEIGHT OF SIMILAR PARTS ON BOEING 767 IS 2860 LB)

U.S. AEROSPACE MATERIAL CONSUMPTION ESTIMATES



TOTAL U.S. AIRCRAFT PRODUCTION

	1944	1978		
TOTAL A/C BUILT	96,000	19,960	MIL AV	964
			TRNSPT	244
			HELIOS	935
			GEN AV	17,817
TOTAL WT	1100 MLB	86 MLB		
TOTAL EMPLOYEES	1.1 M	0.53 M		
TOTAL VALUE ($1978)	$32 B	$11.3 B		
AVG VALUE, 1978 $/LB	$29	$131		
PRODUCTIVITY PERSON-HR/LB	2.8	11.1		

P42-18

AEROSPACE MATERIAL PRICES
1981

	MATERIAL	PRICE, $/LB	BUY-TO-FLY RATIO (TYPICAL)	FLYAWAY COST, $/LB
CONVENTIONAL TECHNOLOGY	ALUMINUM	1.80-2.2	8.0	15
	STEEL (PH STAINLESS)	2.70	5.0	14
	TITANIUM	16-31	6.0	100
ADVANCED TECHNOLOGY	GRAPHITE/EPOXY TAPE	38-55	1.3	60
	GRAPHITE/EPOXY CLOTH	70-80	2.0	150
	BORON/EPOXY TAPE	242	1.25	300
	TITANIUM-NEAR NET SHAPES	25-40	1.5	53
	TITANIUM-SPF/DB	16-31	2.0	50
	B/B_4C/TITANIUM	600-1000	1.2*	1000

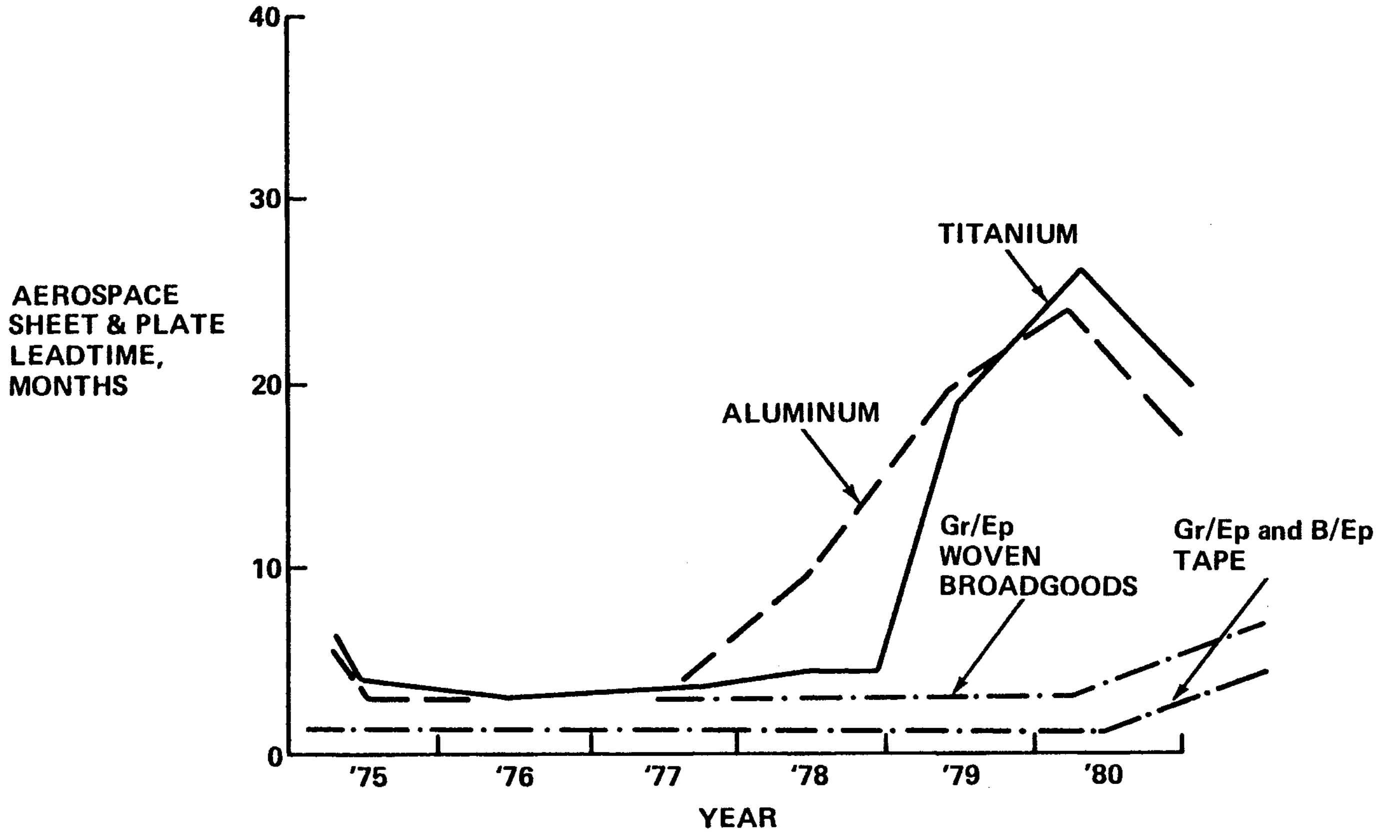
*WHEN USED AS SELECTIVE REINFORCEMENT

ENERGY REQUIREMENTS

		ENERGY (10^3 BTU/FLYAWAY LB)				
		RAW MATERIAL				
	MATERIAL	BILLET	BUY-TO-FLY RATIO (TYP)	SUBTOTAL	CONVERSION (TYP)	TOTAL
CONVENTIONAL TECHNOLOGY	ALUMINUM	108	8.0	864	64	928
	STEEL	19	5.0	95	260	355
	TITANIUM	185	6.0	1110	258	1368
ADVANCED TECHNOLOGY	COMPOSITES	40	1.5	60	78	138
	TITANIUM-SPF/DB	185	2.0	370	160	430

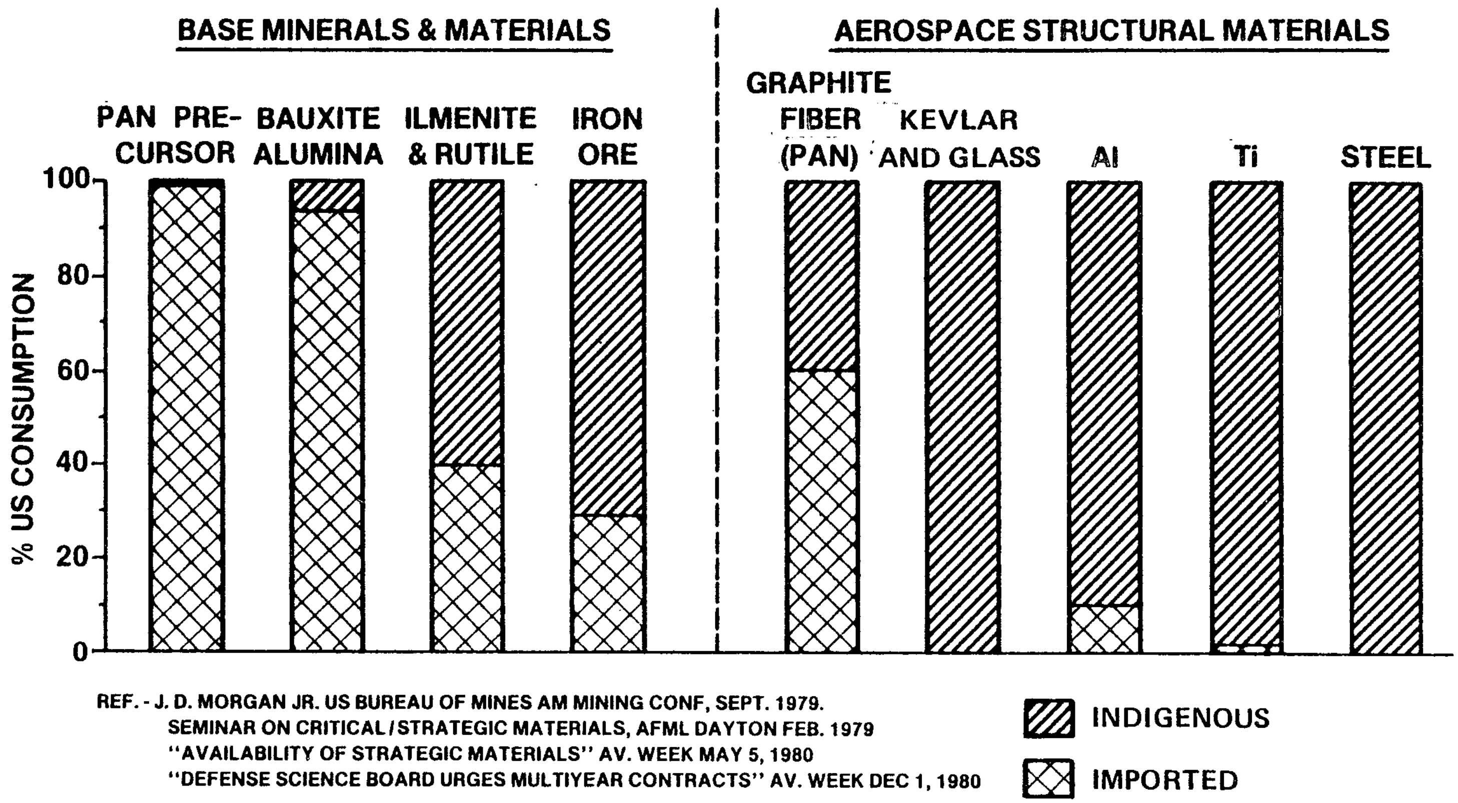
P42-20

AEROSPACE MATERIAL LEADTIMES - SHEET AND PLATE



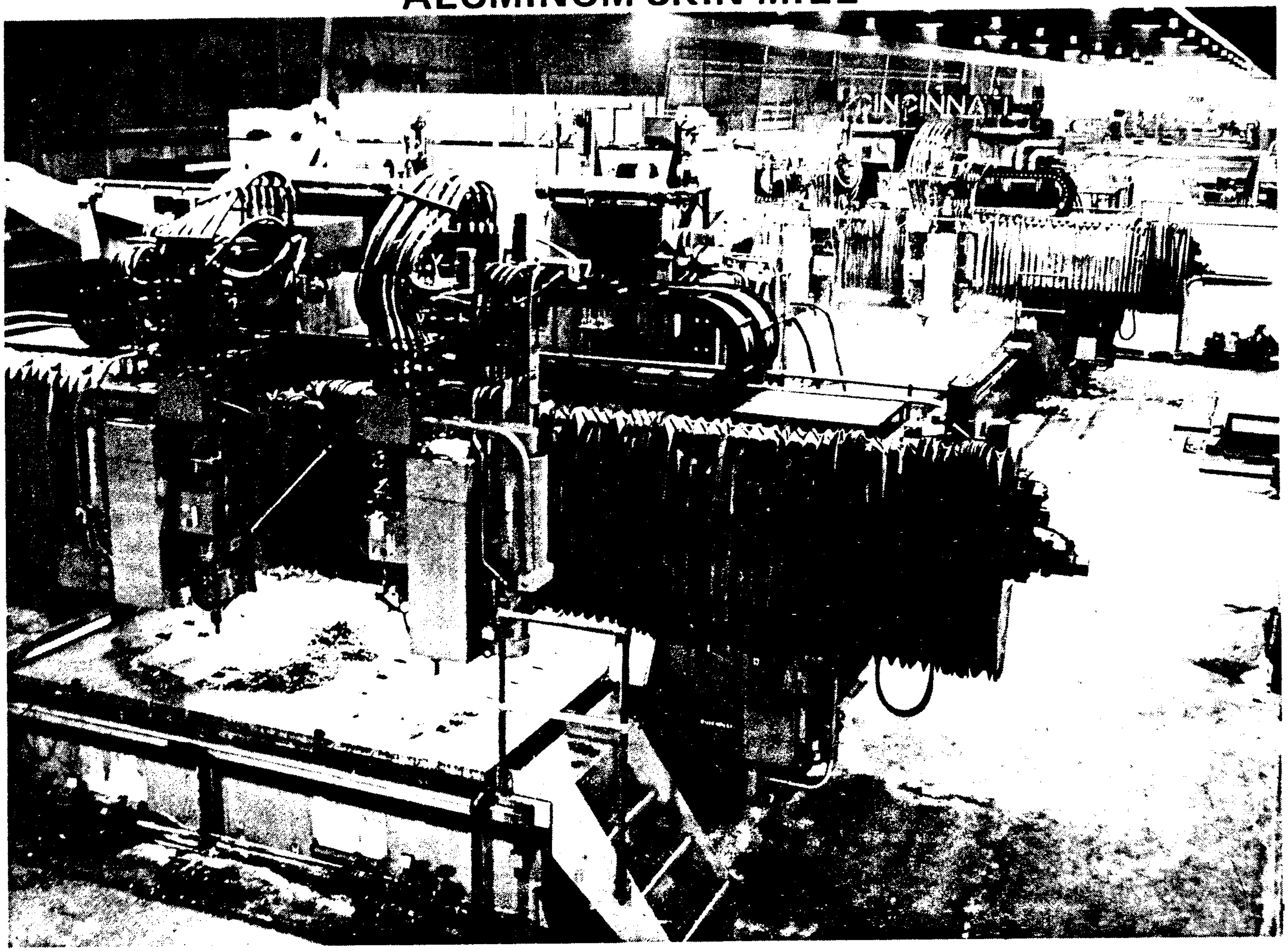
P42-21

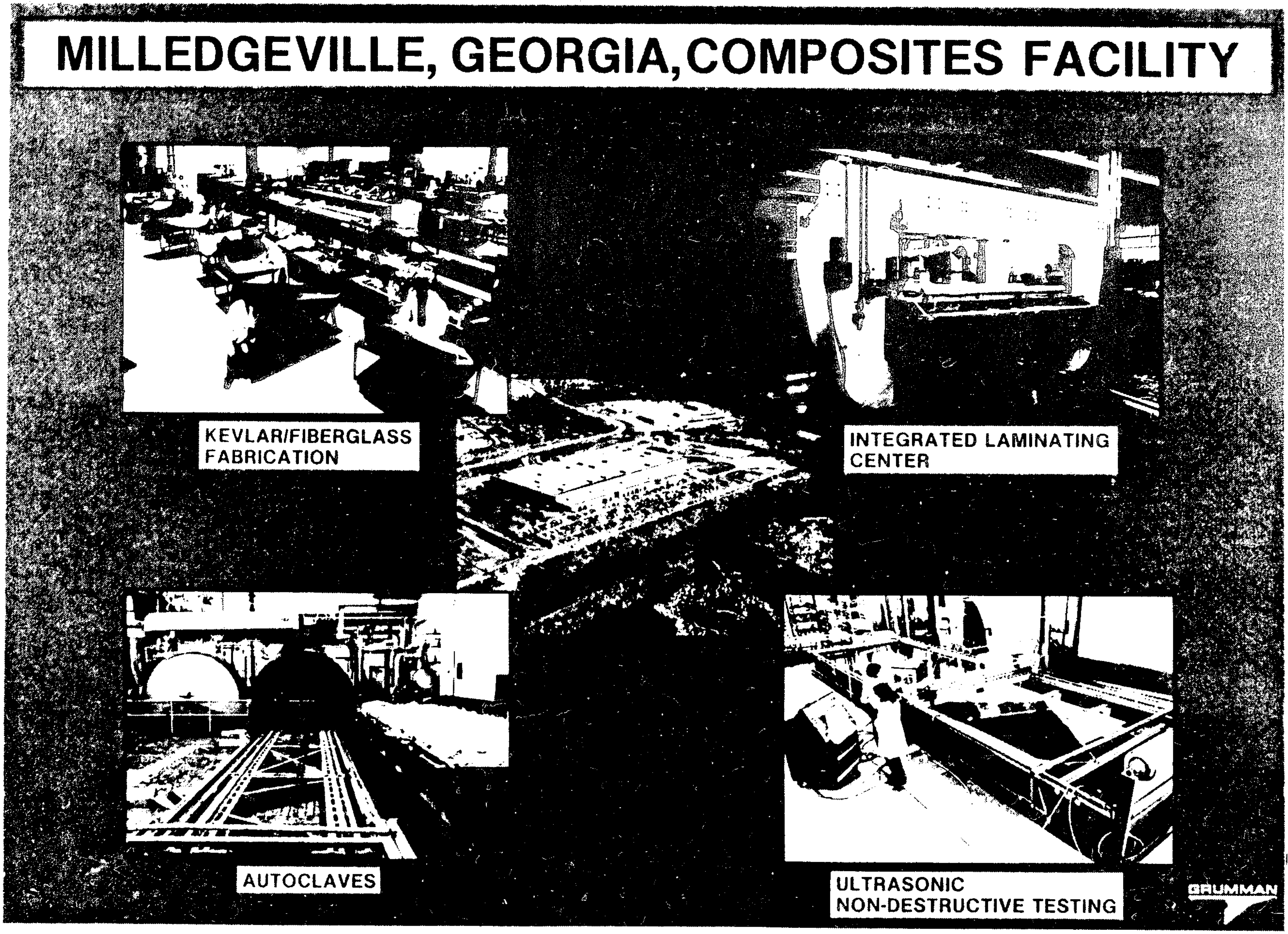
U.S. AEROSPACE STRUCTURAL MATERIAL AVAILABILITY (1980) INDIGENOUS/IMPORTED

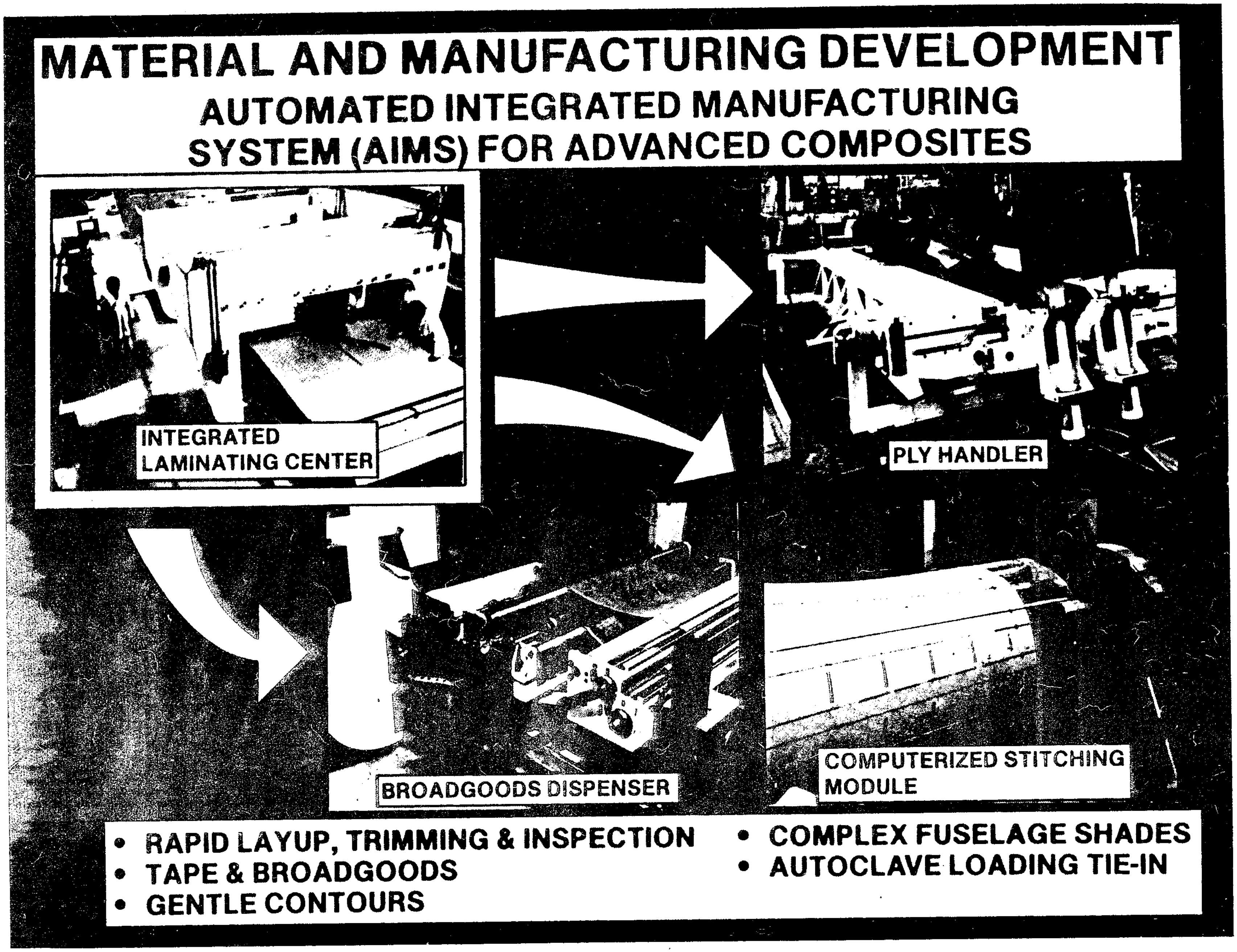


REF. - J. D. MORGAN JR. US BUREAU OF MINES AM MINING CONF, SEPT. 1979.
SEMINAR ON CRITICAL/STRATEGIC MATERIALS, AFML DAYTON FEB. 1979
"AVAILABILITY OF STRATEGIC MATERIALS" AV. WEEK MAY 5, 1980
"DEFENSE SCIENCE BOARD URGES MULTIYEAR CONTRACTS" AV. WEEK DEC 1, 1980

ALUMINUM SKIN MILL




MILLEDGEVILLE, GEORGIA, COMPOSITES FACILITY
KEVLAR/FIBERGLASS FABRICATION
INTEGRATED LAMINATING CENTER
AUTOCLAVES
ULTRASONIC NON-DESTRUCTIVE TESTING
GRUMMAN


MATERIAL AND MANUFACTURING DEVELOPMENT
AUTOMATED INTEGRATED MANUFACTURING SYSTEM (AIMS) FOR ADVANCED COMPOSITES
INTEGRATED LAMINATING CENTER
PLY HANDLER
BROADGOODS DISPENSER
COMPUTERIZED STITCHING MODULE
• RAPID LAYUP, TRIMMING & INSPECTION
• TAPE & BROADGOODS
• GENTLE CONTOURS
• COMPLEX FUSELAGE SHADES
• AUTOCLAVE LOADING TIE-IN

MANUFACTURING CONSIDERATIONS

	METALS	COMPOSITES
STORAGE	• WAREHOUSE	• REFRIGERATOR
COMPONENT PART	• MATERIAL REMOVAL VIA PROFILE MACHINING • FURNACE HEAT-TREAT /STRESS RELIEVE	• MATERIAL BUILD-UP VIA LAYUP AND AUTOCLAVE OR OVEN CURE • OVEN POST CURE
ASSEMBLY	SIMILAR	
QUALITY ASSURANCE ESTABLISHMENT	INCOMING MATERIAL	COMPONENT PART

GRUMMAN

P42-27

SUMMARY

- COMPOSITES WILL CONSTITUTE LARGER PROPORTIONS OF AIRFRAME WEIGHT ON FUTURE MILITARY & COMMERCIAL AIRCRAFT
- AIRCRAFT WEIGHT, SIZE, AND LIFE CYCLE COSTS CAN BE APPRECIABLY REDUCED
- COMPOSITE MATERIAL ENERGY REQUIREMENTS ARE SIGNIFICANTLY LOWER BUT FLY-AWAY MATERIAL COSTS ARE HIGHER THAN ALUMINUM AND STEEL
- OVERALL AEROSPACE UTILIZATION OF STRUCTURAL COMPOSITES WILL INCREASE BY AN ORDER OF MAGNITUDE DURING THIS DECADE BUT ALUMINUM AND TITANIUM USAGE WILL NOT BE SIGNIFICANTLY AFFECTED BY COMPOSITES

POTENTIAL FOR SUBSTITUTION IN ALL USES OTHER THAN AIRCRAFT/AEROSPACE

John P. Riggs
Celanese Corp.

THE ROLE OF COMPOSITES IN SUBSTITUTION, CONSERVATION, AND DISPLACEMENT OF CRITICAL MATERIALS:

<u>POTENTIAL FOR COMPOSITES SUBSTITUTION IN ALL USES OTHER THAN AIRCRAFT/AEROSPACE</u>

DR. JOHN P. RIGGS

TECHNICAL DIRECTOR, STRUCTURAL COMPOSITES

CELANESE CORPORATION

PRESENTED AT

THE WORKSHOP ON CONSERVATION AND SUBSTITUTION TECHNOLOGY FOR CRITICAL MATERIALS

VANDERBILT UNIVERSITY

NASHVILLE, TENNESSEE

JUNE 17, 1981

WORKSHOP ON CONSERVATON AND SUBSTITUTION TECHNOLOGY

FOR CRITICAL MATERIALS

POTENTIAL FOR COMPOSITES SUBSTITUTION IN ALL USES OTHER THAN AIRCRAFT/AEROSPACE

J. P. Riggs

Celanese Corporation

(June 17, 1981)

My objective in this overview is to provide some perspective on the utilization of composite materials in structural applications other than those in aircraft/aerospace end uses; and to tie together some of the points previously made. Specifically, these uses encompass recreational, marine, general industrial, and transportation market segments--with principal emphasis being on the latter two. As indicated in the first slide, these objectives include the following: Provision of a broad outline of the types of nonaerospace applications and the reasons for use of high performance composites (in this instance focused in the main on carbon fiber reinforced organic matrices); delineation of the different constraints on the technical and economic impact of high performance composites in industrial and automotive applications versus those in aerospace; and finally, key needs and issues needing resolution for full realization of the potential of structural composite materials in these types of applications.

In nonaerospace areas, broad, direct impact on utilization of the most critical materials is minimal, although there can be very significant influence on the use of various alloys of aluminum and steel, and

potentially magnesium. In addition--as should become evident--the materials form and manufacturing technology being developed to support cost effective application in nonaerospace sectors may ultimately spin back to provide broadened utilization at lower cost in that sector.

As has been indicated by the previous speakers, over the last decade, fiber reinforced composites have emerged as a new class of structural materials, offering attractive--indeed unique--combinations of static and dynamic properties at significantly reduced weight and overall energy consumption (from component manufacture through life cycle costs in end-use applications). Also, because of the anisotropic nature of the systems, the variety of reinforcements and matrix materials, and the state of current computer assisted design techniques, they provide an unparalleled opportunity for tailor-making such materials for a broad spectrum of applications. The development of higher performance (compared to glass) reinforcements such as carbon fiber, aramids, and silicon carbide have resulted in composite systems with performance characteristics exceeding those of metals, and the use of glass in high loadings as a chopped and/or continuous reinforcement is developing rapidly expanding uses for this material in structural applications. The combination of end-use incentives and reinforcement materials availability is also driving the development of much improved resin matrix systems, with the latter contributing a combination of strain, impact, and environmental durability characteristics that will permit composite utilization in areas as demanding as primary aircraft structure. All of this is being built on a foundation of over forty years' experience with fiber glass reinforced materials.

Chopped glass or woven fiber glass mats, impregnated with resin, have been used for many years in the manufacture of fiberglass boats and other recreational

vehicles, and continuous filament glass wound fishing rods have also been common for some time. Utilization of composite materials in these types of uses have been significantly extended through the use of graphite and aramid (Kevlar®) reinforcements; these provide not only lighter weight, but increased sensitivity, responsiveness, and damping characteristics in fishing rods and various racquets; boats using carbon fiber masts--and other rigging--are repeatedly winning major competitions. Regardless of the various therapeutic claims made for these applications, the technical merits are generally sound, and provide an interesting use of a combination of composite characteristics; but, however, with negligible effect on metals usage.

By far, the most dramatic potential for the use of these materials in nonaerospace areas, and for the large-scale replacement of metals, lies in automotive and industrial applications. To put this in some perspective, in 1980, on the order of 700 million pounds of fiber glass reinforced plastics were used in the transportation industry--and this is projected to grow to 1 billion pounds in the next several years--essentially all in nonstructural applications, and the potential for use in structural areas--with a variety of reinforcements--could add very substantially to these numbers. The basic incentives and performance characteristics that have resulted in expanding use of these materials in the aerospace industry apply to industrial and automotive applications but, as indicated on the next slide, there are a significantly different set of constraints on the technical and economic impact in the two areas: The factors that are critical to widespread use in industrial and automotive applications are primarily cost related, and include the cost of the reinforcement, the concept of hybridization (combining minimal levels of higher performance, higher cost reinforcements with lower performance, lower cost fibers),

high throughput fabrication capability, and fully optimized composite design. These differ from those in aerospace/aircraft in sensitivity to materials costs, fabrication methods, production rates, product form requirements, and the absolute level of mechanical performance necessary.

The fabrication issue can be simply depicted as shown on the next slide: The aerospace industry--in which major structural use of composite materials had its genesis and has its learning curve--is characterized by low production volumes and high labor intensity, as represented by hand lay up procedures and long cure cycles; although, as manufacturing demands increase, emphasis is also being given here to lower cost, higher rate manufacture. Cost effective use in industrial/automotive applications necessitates a quantum change in manufacturing rates and methods, with attendant major implications on types of resin systems used, product forms, control of fiber placement and orientation during the manufacturing process, and quality assurance.

Consider now a second aspect of maximizing cost effectiveness: hybridization. Successful use of hybrid composite materials is extremely significant to major penetration of these high volume, cost sensitive markets, and the next slide depicts a representative hybrid material form that meets the objectives of reducing cost by minimizing the percentage of high performance reinforcement (carbon fiber in this case), maximizing performance by optimizing carbon fiber placement, and creating a product form amenable to high speed fabrication. This is effected by placing unidirectional carbon fiber on the surface of a hybrid molding compound with a comparatively cheap chopped glass core. The relative content of the various materials making up this type of hybrid are typically 10 to 12 percent carbon fiber, on the order of 60 percent glass, and 30 percent resin.

It is key to note that the materials cost of this kind of construction is not much different than that for other high performance polymeric materials and these relatively small amounts of carbon fiber result in major increases in performance characteristics such as tension and flexural stiffness; similar conclusions also apply to fatigue endurance, for example.

There has been extensive prototyping of automotive components in carbon fiber and hybrid materials, although this is now reduced, and the extent of what has been done is, perhaps, best represented by the widely publicized program completed by Ford in 1979 where they undertook to build an experimental car with body, chassis, and powertrain components from carbon fiber composites to the maximum extent. A schematic breakout of this vehicle is shown in the next slide: In constructing this car, about 160 parts were made in carbon fiber reinforced composites, resulting in a total weight save of over 1200 pounds (706 lbs by direct materials substitution, 540 lbs as a result of secondary weight reduction), and an increase in fuel efficiency of 33 percent. Since this program--which was focused on concept and materials feasibility as opposed to primary manufacturing and cost considerations--further analysis and prototype demonstration has shown that, depending on vehicle, type of component, and hybrid utilization, <u>material</u> cost penalties of $1.50 to $0.70 per lb. of weight saved are quite realizable with carbon fiber composites (with fiber prices at levels well below those available today). Equally important to realize is that the thrust to use composite materials for weight reduction is also leading to extensive evaluation of glass only systems--both unidirectional and high glass content chopped systems--in structural applications, and that these can be highly cost/performance effective (for example in certain leaf springs)--less weight saved but substantially reduced cost. These points are

illustrated in the next slide comparing the use of glass and carbon composite materials in generic structural types for a specific vehicle. The net result is that with the growing depth of understanding of the performance characteristics, and advantages, of these materials, and the availability of sophisticated design techniques which permit that definition of the total stress environment for anisotropic systems as well as multiple material optimization--the latter including both hybrids and combinations of metallic/composite constructions--there continues to be substantial effort in this area. All glass structural applications using continuous fiber, or mixtures of continuous, unidirectional and short fiber in random orientation, are going into production, and a number of carbon/glass hybrid components are nearing semiproduction trials. In Europe, the emphasis is more intensive.

Realization of this full potential for truly dramatic weight savings opportunities in the highly cost sensitive transportation industry--and the attendant implications for large substitution of metallic materials--is, however, contingent on a number of key factors, as outlined in the next slide. These include:

- o Reinforcement cost
- o The ultimate selection of weight targets for a given space envelope, which will dictate the use of certain materials for design of vehicles with optimum capacity and utility at minimum weight.
- o Further development of design and materials methodology to pursue maximum effectiveness in utilization of inherently anisotropic systems.
- o Better understanding of performance characteristics in service and failure modes.
- o Development of low cost, high volume manufacturing processes.

- Resolution of problems in bonding and joining methods, including dissimilar materials.
- Development of higher rate methods of nondestructive testing readily applicable to quality control.
- Further quantification of the crash-worthiness of composite materials.

Turning now to some other aspects of the general industrial market, recall that continuous filament reinforcement (glass and aramid) of plastic matrices have been used to a significant extent for various types of pressure container and piping applications where high specific strength is the principal mechanical performance requirement, and light weight and corrosion resistance are also often significant objectives. This general type of application is being extended to the transportation industry in the filament winding of railroad tank cars. With respect to the utilization of higher performance reinforcements, the current thrust and future potential is briefly summarized in the next slide: At present, the most significant use of carbon fibers in industrial applications is in chopped reinforcement of thermoplastic molding compounds, with performance emphasis on static dissipation (due to the electrical conductivity of carbon fiber) and lubricity; these systems also take advantage of the well developed, low cost manufacturing advantages of injection molding. Typical applications include data printer parts, ignition components, and x-ray tables and cassettes--the latter of which exploit the x-ray transparency of carbon fiber composites permitting lower intensity radiation to the patient. Projected future applications in this segment, which include oil drilling equipment, agricultural equipment, heavy machinery, and chemical plant equipment, take broader advantage of composite performance characteristics, i.e., structural rigidity and light weight, fatigue resistance, reduced inertial resistance for high speed reciprocating and rotating action, and chemical and corrosion resistance.

In summary, the principal nonaircraft/aerospace applications of high performance composites cover a very broad range of existing and potential uses in diverse market segments--marine, recreation, transportation, and industrial. The former two represent areas of well established applications; the latter two encompass more limited use at present, but have the greatest volume potential. Indeed, with respect to the latter, full resolution of the major issues--reinforcement cost; fully optimal use of hybrid systems; development of high speed, automated manufacturing processes that permit reliable control of fiber placement and orientation--could result in larger scale use and substantial metal replacement.

SUBSTITUTION PREPAREDNESS-
INFORMATION STOCKPILE ON SUBSTITUTION TECHNOLOGY

A. O. Schaefer
Metal Properties Council

KEYNOTE ADDRESS

SUBSTITUTION PREPAREDNESS
INFORMATION STOCKPILE ON SUBSTITUTION TECHNOLOGY

BY

A. O. Schaefer
Executive Director
The Metal Properties Council Inc.

Substitution Preparedness - Information Stockpile on Substitution Technology.

Requirements for an information stockpile on substitutes for critical materials. How should it be developed? Mechanism for storage and dissemination of technological information on substitution. How does it relate to existing information sources?

It is important to me to state at the onset that I believe I have certain very definite qualifications for being on this program. I was part of the war effort thirty-five or more years ago when we faced the problems of inadequate supply of alloying elements. There was an industry committee organized by the War Production Board that was known as the "Bent Committee" because it was chaired by one Quincy Bent, then Vice President of the Bethlehem Steel Corporation.

The word computer in its present sense was unknown. We had not yet come to the recognition that the supply of the good things on this earth was not unlimited, but we did know that we didn't have the capacity to acquire the supplies of the alloying elements we would like to have in time to meet scheduled demands. Furthermore, the Nazi and Japanese submarines made ocean shipments precarious.

Strangely enough I don't recall any problems with chromium. We were short of vanadium for a while because it had

to come all the way up the West Coast of South America. In the latter days of the war we lacked columbium because we didn't know where to find it.

But we were in relatively short supply in everything, and we attempted to control the distribution to where it would be the most needed. The NE steels and their role has been referred to by others at this meeting. The "leaner alloy" principle was widely practiced. The experience leads me to one conclusion which I think has a bearing on our consideration of our planned information system.

The properties we thought we needed of the NE steels and the other leaner alloys, were rather easily obtained (life was simpler in those days), -- but the manufacturing technology and the plant equipment needed to get the necessary results with the leaner alloys was the major problem, and we had many meetings and plant visitations by experts to teach how to get the necessary results with leaner alloys. The exchange of technology, not properties of substitute materials, was a major problem and I think we should be aware that there will again be problems in this respect.

Briefly, as an example, here was the requirement for cannon barrels. We needed more of them, of lighter weight, capable of utilizing more powerful explosive charges, producing higher muzzle velocities, and having lower alloy content. We did it by

bettering our melting, forging, and heat treating operations, -- and there was a great exchange of technology both here and in Britain to accomplish it.

Now for today. We are of course, discussing a popular subject. Our public, at least the engineering public, is aware that resources are dwindling. They are aware the materials we need may be cornered in unfriendly hands. Outside of the metallurgical fraternity, there may not be awareness of the extent to which this applies to our raw materials, but we have some basic public awareness to build on.

Our technical societies have addressed this problem, and the American Society for Metals is in the forefront of this activity. I am sure Dave Chafe will tell you of this.

My present experience is with The Metal Properties Council, Inc., where we have one important task group on the Use of Computers in Managing Material Property Data. One of our panelists is a colleague of the chairman of that Task Group, Jim Graham.

MPC has another task group on "Critical Materials" which is chaired by Ray Lula, whose name has appeared in our discussions here. This group has reported to ASM's committee on this same subject. It was organized, at the request of several members to consider what might need to be done with respect to

substitute materials. The principle interest of course, would be the engineering properties of such materials. MPC would feel a responsibility to state what data was needed to proceed to obtain it, validate it, and make it available where it is needed.

This young Task Group, several members of which are attending this conference, has announced two conclusions which I think should be more widely known, and which are pertinent to this discussion.

The first of these is that we should not confuse the two quite different aspects of the critical materials problem. The one aspect is that of the critical materials situation which would come from a war or similar crisis of finite and limited duration. The second is the long-range problem based on the ever-shifiting economic and political situation and the world supply of critical materials.

The first is more acute; but, in many respects, the simpler phase of the problem. The second is certainly more complex, and presents us with entirely new situations.

The second pronouncement of the MPC Committee has to do with stockpiling and need not concern us at this session. The long range situation is one which requires better appreciation

of the problem on the part of all elements of our population. Societies such as the American Society for Metals, government bureaus such as the Department of Commerce and the Department of the Interior must continue to impress the public with the facts of the situation, with the knowledge of our dependance on foreign sources for many of our metals. Effective efforts for conservation, innovation in substitution can only be expected when there is widespread appreciation of the situation. This does not involve information—stockpiling of the type contemplated in the title of this session. Our attention today, is quite similar to that of our MPC task group, it must be directed to making readily available to those who will use it, the properties of all possible substitute materials.

Before embarking on long-range planning for the information stockpile on critical materials, let us make clear that we should recognize the difference between the standardized and static information which rightly belongs in handbooks and forms a necessary base for our information.

We are more concerned, I think, with the advancing front of new knowledge of the properties of materials. The accumulations of new data for which we have new and effective tools for evaluation. It is expressed in this sentence borrowed from a recent issue of a British publication, "Materials in Engineering"

"Optimization of design and specification
of engineering components and systems to meet

life cycle demands in terms of initial, through costs, and acceptable safe life, demands a greater knowledge of long term material properties and residual safe life than can be derived from conventional property data."

This to me explains why we have expanding programs of ever more sophisticated testing producing data which is subjected to more revealing analysis. This is taking place today with conventional materials. It will take place with substitute materials.

The problem is to analyze and evaluate data properly, and to make it readily available. This is exactly our problem with substitute.materials.

It is well to consider briefly some of the efforts that have been initiated in this field as an introduction to today's discussion. The American Society for Metals has been outstanding as one of our major technical societies offering extensive handbook and computer information services. Other technical societies have similar activities. We will not enumerate here all of the data sources available to us today.

We should mention a review and report which was conducted by a committee organized by the Numerical Data Advisory Board of the National Research Council which was chaired by Mr. James Graham, who is also chairman of the MPC task group and whose colleague

appears on our program today. Their report, published in late 1980, is entitled "Mechanical Properties Data for Metals and Alloys: Status of Data Reporting, Collecting, Appraising, and Disseminating."

A listing of the members of the Committee appears as Figure 1 and you will note the participation of many present at this conference. Furthermore many present today from various government bureaus, notably from the Bureau of Standards and from the Department of Defense met with this committee and explained their activities and interest.

I think it is pertinent to today's discussions to extract from the very important report of this Committee, two of their conclusions. These are shown in Figures 2 and 3.

These should be considered in planning activity in this area.

Another interesting publication of The American Society of Mechanical Engineers, will be available next week at the meeting of the Pressure Vessel and Piping Division of that Society. It is entitled "Critical Issues in Materials and Mechanical Engineering" and is identified by ASME as PVP Vol. 47.

Section 1.2 of this document is entitled "The Role of

Engineering Judgment and the Computer in the Management of Material Property Data." The activity reported in this book was chaired by Dr. Jeffrey Fong of the National Bureau of Standards. The section in question emphasized the fact that great value must be placed on engineering judgment in the evaluation of metal properties and I would join in this opinion which is based on genuine experience. One of the commentators in the book expresses it in this form. "The management of the computer system must reside in those familiar with materials and understanding the meaning of the property data, rather than with the computer technologist per se."

I would like to mention one more publication which is available because several of the members of this panel contributed to it, and expressed their thoughts in it. It is entitled "The Use of Computers in Managing Material Property Data." It is an ASME publication, identified as MPC-14. A look at the title page indicates the participation of members of this panel. It is shown in Figure 4.

I hope that these remarks will prepare you for the opinions and statements of the experts you are about to hear. The needed information necessary to stockpile consists of (1) the availability of materials, and (2) developments on substitutions for scarce materials.

PANEL ON MECHANICAL PROPERTIES DATA FOR METALS AND ALLOYS

James A. Graham, Chairman Deere & Company Technical Center	(Metal Properties Council)
Herbert L. Black Universal Cyclops Specialty Steel Division Cyclops Corporation	(Steel industry)
M. K. Booker Oak Ridge National Laboratory	(Nuclear materials)
Paul Brister Babcock & Wilcox	(American Society of Mechanical Engineers)
Herbert Corten University of Illinois	(University)
Stewart Fletcher American Iron & Steel Institute	(Steel industry)
W. J. Harris Association of American Railraods	(Rail industry)
Ronald Landgraf Ford Motor Company	(Society of Automotive Engineers)
Joseph F. Libsch Lehigh University	(Federation of Materials Societies) (American Society for Metals)
Art Lowe Babcock & Wilcox	(Nuclear design)
Adolph Schaefer Metals Properties Council United Engineering Center	(Metal Properties Council)
Henry Stremba American Society for Testing and Materials	(Deputy Managing Director, American Society for Testing and Materials)

CONCLUSION NO. 3

THE PANEL STRONGLY RECOMMENDS THAT MECHANICAL-PROPERTIES DATA BE ADDRESSED THROUGH THE ESTABLISHMENT AND MAINTENANCE OF SEVERAL SPECIALIZED DATA BANKS DEVELOPED BY TECHNICAL EXPERTS, RATHER THAN BY A SINGLE ALL-ENCOMPASSING ONE. SUCH SPECIALIZED DATA EFFORTS SHOULD BE COORDINATED. THE PRESENT DATA-BASE MANAGEMENT SYSTEMS BEING DEVELOPED BY THE METAL PROPERTIES COUNCIL AND THE DATA PROGRAMS AT BATTELLE, OAK RIDGE NATIONAL LABORATORY, AND INDUSTRIAL AND OTHER ORGANIZATIONS SHOULD BE CONTINUED AS A PART OF SUCH A COORDINATED SYSTEM.

CONCLUSION NO. 7

WITH THE ADVENT OF COMPUTER-AIDED MANUFACTURING AND AUTOMATED PROCESSING, DATA BASES MUST INCLUDE THE MECHANICAL PROPERTIES AND TEST METHODS THAT HAVE BECOME INCREASINGLY IMPORTANT IN THE PLANNING OF MANUFACTURING PROCESSES AND IN THE CONTROL OF THESE PROCESSES TO ASSURE CONTINUOUS QUALITY PRODUCTION.

CONTENTS

INFORMATION ANALYSIS CENTERS AND SUBSTITUTION TECHNOLOGY

Harold Mindlin
Battelle Columbus Laboratories

INFORMATION ANALYSIS CENTERS
AND
SUBSTITUTION TECHNOLOGY

Paper to be presented at the
Workshop on Conservation and Substitution
Technology for Critical Materials

15-17 June 1981

Vanderbilt University
Nashville, Tennessee

by

Harold Mindlin
Manager, Materials Information Program Office
Battelle's Columbus Laboratories
505 King Avenue
Columbus, Ohio 43201

INFORMATION ANALYSIS CENTERS
AND
SUBSTITUTION TECHNOLOGY

by

Harold Mindlin

The Metals and Ceramics Information Center and the Mechanical Properties Data Center have been in operation since 1956 and 1960, respectively (Slide 1)*. These Department of Defense full-service Information Analysis Centers (IAC) have become resources used by the government, industry, and academic technical communities for the rapid retrieval of materials information and data. With the relatively recent move toward computer-aided design and manufacturing, the selection of materials becomes another facet of the process needed to produce efficient structures and components that must operate under various conditions in a variety of environments. The information and data in these two Centers provide a data base that can become an integral and essential part of any materials system designed to accelerate and facilitate conservation and substitution.

It is the objective of this talk to describe current activities and suggest alternatives and data base modifications that will extend the usefulness of these Centers within the current levels of technology displayed by the mechanical properties numeric data base. Keeping in mind that a modified MPDC/MCIC data base can become part of an integrated computerized system, the problems of substitution and conservation, the topics of this conference, will be addressed.

The objective (Slide 2) of all the Information Analysis Centers is the increased productivity of the technical community involved in scientific and engineering programs. Through the collection, review, analysis, appraisal, and summarization of the available data, scientific and technical information is made available to the Centers' users.

---

*Copies of slides are attached.

These steps in the processing of technical information obtained from a number of sources (Slide 3) permit the evaluation of the data to occur at several stages--from review of incoming data in its original form by qualified technical personnel and information specialists to the review necessary for the summaries which are produced in a number of formats.

For aerospace and other alloys of concern to the DoD, the foregoing sources are reviewed to provide authoritative (and evaluated) information (Slide 4) on design characteristics, applications, processing, fabrication, quality control, environmental effects, test methods, sources (suppliers) and specifications.

In order to gather this information and make it available to all potential users, the operation of each of the Centers is divided into three task areas (Slide 5)

1. Establishement of the data base--including (a) acquisition and input of source information (b) initial review for pertinence to overall scope (c) evaluation and extraction of data and information and (d) inputting of data into appropriate data system (MCIC or MPDC)
2. Products and Services
   a. Technical handbooks and databooks (our current listing contains about 15 titles)
   b. State-of-the-art reports (more than 40 titles)
   c. Critical reviews and technology assessments (on request)
   d. Responses to technical inquiries (about 270 per year)
   e. Responses to bibliographic inquiries
   f. Special studies and tasks (about 14 on the current contract totalling about $1.4 million)
3. Public Relations
   a. Current Awareness Bulletin (issued monthly with emphasis on DoD activities)
   b. Promotion and sales (sale of Handbooks and State-of-the-Art Reports permits additional technical activities)

After the information is reviewed, key-worded, abstracted, etc., it is entered into a common bibliographic data base (Slide 6). In addition if there is numeric and sufficient characterization data on the mechanical properties of alloys of interest to the Centers the data are entered into the Battelle system. The bibliographic data is entered into the Defense RDT&E On-Line System at the Defense Technical Information Center through two terminals at Battelle. This information then becomes available to anyone having access to the DTIC system or through the services provided by MCIC. The numeric data base on the Battelle computer is managed by Battelle's Automated Search Information System (BASIS), a versatile (proprietary) data management system. BASIS has many features that permit ease in searching, on-line editing, sorting, and report generation. Data manipulation, statistical analysis, file creation, saving of user procedures can be handled by the system. Battelle's computer is accessible through TYMNET, an international telecommunications network. Although MPDC can be addressed through TYMNET, that service is not yet available. It is hoped that in the future the MPDC data base will be made available to outside users.

The remainder of this presentation will focus on the operating system and contents of the MPDC numeric data base with the intent of showing, by example, the inherent capabilities of BASIS as it is applied to the problems of data storage and retrieval. The mechanical properties numeric data base is currently comprised of two separate sections that eventually will be combined (Slide 7). The Thesaurus is an Alloy Cross Index (that is available in published form) set up on an alloy numbering system unique to MPDC. Originally this was done to facilitate searching of the data base. The Thesaurus contains U.S. and foreign specifications, chemical compositions, common nouns, and other descriptive terms, etc., of many alloys--all related through the MPDC number.

The main portion of the numeric data base are the data files that contain

--Source identification

--Material identification and/or characterization

--Specimen, test, and environment descriptions

--Test data (for individual specimens).

To illustrate the ease with which the data base can be queried, a search example (Slide 8) is given to retrieve tension data (1) for a bar (2) material having less than 20 percent chrome (3) at test temperatures of 60-80F. For this example, there are 20 records that the search criteria (Set 6) identified as having one or more sets of specimen test results. Alternative search routines (Slide 9) based on "AND" statements can be used to arrive at the same results.

A typical record would have all the available information to characterize the material as well as give the data (Slide 10). After the appropriate test results have been identified in the data base, the information can be reformatted to put the data into a more readable form (Slide 11) or data from different reports can be analyzed or reformatted in tabulated or graphical form. As indicated previously, analysis programs (Slide 12) and results can be stored for future reference. In addition, plotting routines are available (Slide 13) to combine data from different records.

With this background, the question "How can similar data and capabilities be applied to solve the problems related to conservation and substitution?" can be posed. MCIC and MPDC have evaluated data from a variety of sources--but, much more is needed if the data are to be used to conserve strategic materials or select possible substitutes or alternatives for an alloy that is in short supply or just not available. As demonstrated with the MPDC example, the computer hardware and software (such as BASIS) are available to facilitate access to extensive quantities of relevant data.

In order to select a "non-critical" material for a specific application, it is necessary to extend the contents of the MPDC data base and define the search parameters. The proper combination of these parameters will then define a usable material providing for an acceptable design meeting design life or environment criteria and/or other restrictions.

As a start, for a given material, this requires an integrated data base containing evaluated data, such as

--Physical Properties

--Product Forms

--Fabricability

--Mechanical Properties

--Service Environment

--Corrosion Resistance.

Within each of these categories (Slide 14), the data must be as complete as possible if all aspects of the problem are to be addressed. For example, mechanical properties may be given as specification values or as calculated mean values (with standard deviations) for a representative population (MIL HDBK 5C approach). (This is considerably different than the individual data points given in MPDC.) Additionally, it may be necessary to represent properties, such as fatigue or stress-strain behavior in a mathematical (curve) form. Background information such as test specimen characterization and test description, may be stored, but it is not of direct importance to material selection. One of the key limiting factors of this proposed sophisticated data base is the amount of data and the degree to which it can be evaluated and integrated.

As a relatively simple example (Slide 15), this system could be queried by specifying that the alloy requirements are

1. no chromium
2. weldable (process may be specified)
3. formable

with related strength requirements in a given environment such as

4. minimum yield or fatigue life at a given number of cycles and temperature
5. corrosion resistance

If one remembers that a relatively simple search routine can specify these variables, these parameters can be entered into the system with the results being a list of materials and/or a combination of materials and processes meeting those requirements.

This, and the related physical property data, can then be entered into a computer-aided design process to assure that the structural needs such as minimum weight or life can be achieved. If all goes well, various material sources can be contacted. One or more iterations through the CAD process may be required depending upon material delivery, structural weight, cost, etc. (Factors such as quantity requirements that could affect availability are not addressed in this presentation. Sources and quantity effects could be the topic for another paper.)

As one can easily see, the complexity of the system requires the assembly of a large quantity of evaluated data. A strong materials/structures/information interface is required to produce a system that will be easily accessible, complete, and contain adequate data. Some of the other speakers have described such systems for specific applications; hence, we know that given the proper resources, steps can be made toward the solution of the problems of substitution and conservation.

METALS AND CERAMICS

INFORMATION CENTER

MECHANICAL PROPERTIES

DATA CENTER

FULL-SERVICE INFORMATION ANALYSIS CENTERS

Operated under Contract to

DEPARTMENT OF DEFENSE

By

BATTELLE'S COLUMBUS LABORATORIES

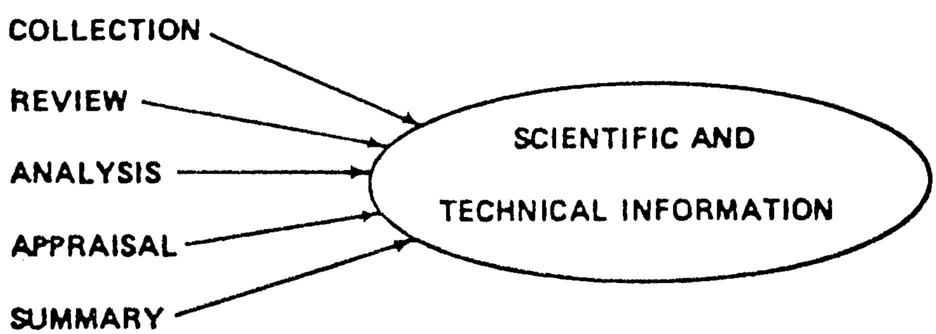
6/25/79

Battelle
Columbus Laboratories

OBJECTIVE

INCREASED PRODUCTIVITY – SCIENTIFIC AND ENGINEERING PROGRAMS

FUNCTIONS



6/25/79

Battelle
Columbus Laboratories

INFORMATION RESOURCES

- GOVERNMENT REPORTS
- CONTRACTOR REPORTS
- U.S. AND FOREIGN LITERATURE
- PUBLISHED AND UNPUBLISHED COMPANY STUDIES
- BATTELLE STUDIES
- INTERVIEWS AND TRIP REPORTS
- TECHNICAL MEETINGS AND PROCEEDINGS

C/25/79

Battelle
Columbus Laboratories

SCOPE

FOR THESE MATERIALS, PROVIDE AUTHORITATIVE INFORMATION

- DESIGN CHARACTERISTICS
- APPLICATIONS
- PROCESSING
- FABRICATION
- QUALITY CONTROL
- ENVIRONMENTAL EFFECTS
- TEST METHODS
- SOURCES, SUPPLIERS
- SPECIFICATIONS

Battelle
Columbus Laboratories

TASKS

ESTABLISHMENT OF THE DATA BASE

- ACQUISITION AND INPUT OF SOURCE INFORMATION

PRODUCTS AND SERVICES

- TECHNICAL HANDBOOKS AND DATABOOKS
- STATE-OF-THE-ART REPORTS
- CRITICAL REVIEWS AND TECHNOLOGY ASSESSMENTS
- TECHNICAL INQUIRIES
- BIBLIOGRAPHIC INQUIRIES
- SPECIAL STUDIES AND TASKS

PUBLIC RELATIONS

- CURRENT AWARENESS
- PROMOTION AND SALES

Battelle

MCIC	MPDC
BIBLIOGRAPHIC DATA BASE	
	MECHANICAL PROPERTIES NUMERIC DATA BASE
DTIC TERMINALS	BATTELLE COMPUTER (BASIS)
DEFENSE RDT&E ON-LINE SYSTEM	TYMNET
OPEN TO DTIC USERS	(FUTURE— ON-LINE)

Battelle
Columbus Laboratories

MPDC NUMERIC DATA BASE

THESAURUS (ALLOY CROSS INDEX)

- SPECIFICATIONS — U.S. AND FOREIGN
- ALLOY SYSTEM
- OTHER TERMS
- MPDC IDENTIFICATION

DATA FILES

- SOURCE IDENTIFICATION
- MATERIAL IDENTIFICATION OR CHARACTERIZATION
- SPECIMEN, TEST, ENVIRONMENT DESCRIPTIONS
- TEST DATA

Battelle
Columbus Laboratories

SEARCH EXAMPLE-1

ENTER YOUR REQUEST

1/TT: TENSION
200 ITEMS SAVED AS SET 1

2/FM: BAR
150 ITEMS SAVED AS SET 2

3/CR 0.0/20.0
75 ITEMS SAVED AS SET 3

4/(1 AND 2 AND 3)
50 ITEMS SAVED AS SET 2

5/TMP 60/80
40 ITEMS SAVED AS SET 5

6/(4 AND 5)
20 ITEMS SAVED AS SET 6

Battelle

SEARCH EXAMPLE - 2

```
ENTER YOUR REQUEST
  TT:  TENSION AND FM BAR AND
   CR 0.0/20.0 AND TMP 60/80
      ITEMS SAVED AS SET
```

ITEM 1

```
 0. ACCESSION NO.    :241499
15. POINTER          :1635
21. NAME             :6419
23. FORM             :BAR-ROUND, 1.875 IN DIAMETER
24. ELEMENT(WT%)     ;NI: ;CR:18.0 ;CO:14.8 ;TI:4.88 ;MO:3.1 ; AL:2.5
                            ;W:1.47 ;FE:0.14 ;MN:0.1 ;C:0.07 ;SI:0.10
                            ;B:0.018 ;ZR:0.04 ;S:0.003 ;
32. PRIMARY OPN      :WROUGHT, FORGED
34. DENSITY          :0.292 LBS/IN(3)
35. HT, TYPE         :PRE-HEAT - SOLUTION TREATMENT - COOL OR QUENCH
                            TO ROOM TEMP
37. HT, OPN 1        :MULTIPLE AGE
38. HT1(F,HRS,MED)   :2150 , 4.0 ,,AIR COOLED TO ROOM TEMPERATURE
40. HT2(F,HRS,MED)   :1975 , 4.0 ,,AIR COOLED TO ROOM TEMPERATURE
41. HT3(F,HRS,MED)   :1550 , 24.0 ,,AIR COOLED TO ROOM TEMPERATURE
42. HT4(F,HRS,MED)   :1400 , 16.0 ,,AIR COOLED TO ROOM TEMPERATURE
54. STR CONC FAC(T) :1.0
56. SPEC THICK (DIA):0.500 INS
57. GAGE LENGTH      :2 INS
58. SPECIMEN CONFIG :ROUND SPEC, LG OF RED. SECT 2.500 IN.
67. TEST TYPE        :TENSION
70. SPEC ORIENT      :LONGITUDINAL
71. TEST RATE        :0.005 INCH/INCH/MIN. IN THE ELASTIC REGION.
                            AFTER YIELD THE HEAD SPEED WAS INCREASED
                            TO 0.1 INCH/MIN. FAILURE.
73. TEST TEMP        :79.9 - DEG. F
78. ULT STRENGTH,KSI:177.000;178.000;178.000;
79. YLD STRESS,% OFF:138.000 - 0.2%; 139.000 - 0.2%; 137.000 - 0.2%;
82. MOD OF ELAST     :30.900 ;27.900 ;28.900 ;
83. ELONGATION, %    :7.20 ;7.70 ;6.70 ;
84. RED IN AREA, %   :7.00 ;9.60 ;9.50 ;
 2/
```

Battelle

MPDC DOCUMENT NO.: 241499
NAME: 6419 FORM: BAR-ROUND, 1.875 IN DIAMETER DOCUMENT: 1635
ELEMENT WEIGHT %: NI: ;CR:18.0 ;CO:14.8 ;TI:4.88 ;MO:3.1 ; AL:2.5 ;
W:1.47 ;FE:0.14 ;MN:0.1 ;C:0.07 ;SI:0.10 ;B:0.018 ;
ZR:0.04 ;S:0.003 ;

PROCESSING INFORMATION

PRIMARY OPERATION: WROUGHT, FORGED
THICKNESS: DENSITY: 0.292

SPECIMEN DATA

NOTCH CONFIGURATION: STRESS CONC FACTOR: 1.0
SPECIMEN CONFIGURATION: ROUND SPEC, LG OF RED. SECT 2.500 IN.

HEAT TREATMENT

TYPE	TEMP,HOURS,MEDIUM,REMARKS
MULTIPLE AGE	2150 , 4.0 ,,AIR COOLED TO ROOM TEMPERATURE
	1975 , 4.0 ,,AIR COOLED TO ROOM TEMPERATURE
	1550 , 24.0 ,,AIR COOLED TO ROOM TEMPERATURE
	1400 , 16.0 ,,AIR COOLED TO ROOM TEMPERATURE

NOTES: PRE-HEAT - SOLUTION TREATMENT - COOL OR QUENCH TO ROOM TEMP

TEST DATA

TEST TYPE: TENSION TEMP: 79.9 - DEG. F THICKNESS: 0.500
GAGE: 2 TEST RATE: 0.005 INCH/INCH/MIN. IN THE ELASTIC REGION. AFTER YIELD THE HEAD SPEED WAS INCREASED TO 0.1 INCH/MIN. FAILURE.
ORIENTATION: LONGITUDINAL ENVIRONMENT:
FAILURE DESCRIPTION:

UTS	YS	ME(*)	EL	RA	PR	HRD(**)
177.000	138.000 - 0.2%	30.900	7.20	7.00		
178.000	139.000 - 0.2%	27.900	7.70	9.60		
178.000	137.000 - 0.2%	28.900	6.70	9.50		

ENTER REPORT DIRECTIVE
/

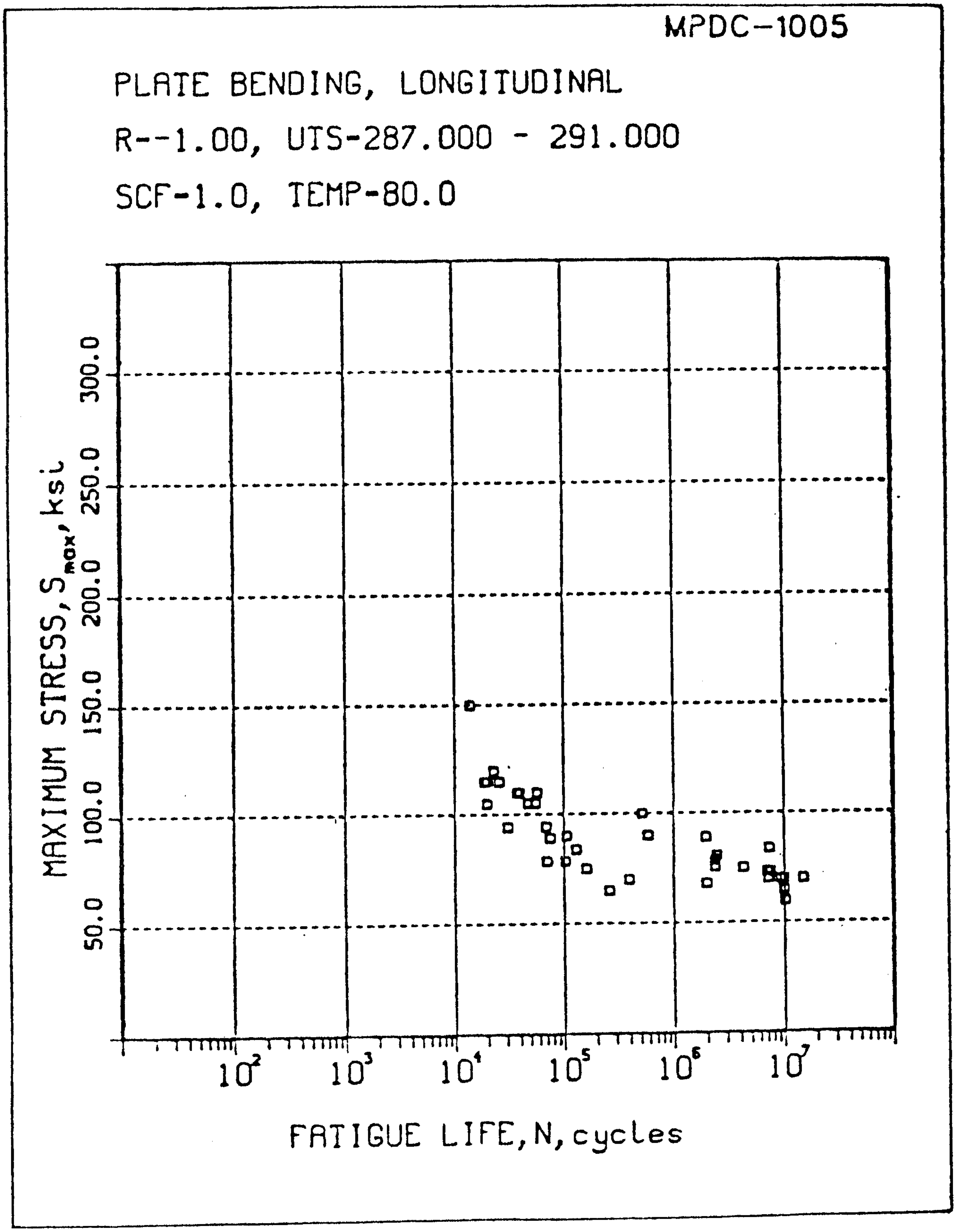
Battelle

DATA ANALYSIS AND PRESENTATION

- STATISTICAL ROUTINES
  - REGRESSION ANALYSIS – PARTITIONING, LEAST-SQUARES
  - CURVE FITTING
  - MEAN, STANDARD DEVIATION, DISTRIBUTION (NORMAL OR NON-NORMAL)
  - A AND B DESIGN ALLOWABLES
- ELEVATED TEMPERATURE RATIOS (MIL-HDBK 5 PROCEDURES)
- COMPARISON OF MATERIAL DATA FOR LOT-TO-LOT VARIATIONS
- MECHANICAL PROPERTY PLOTTING ROUTINES

6/25/79

Battelle
Columbus Laboratories



MPDC-1005
PLATE BENDING, LONGITUDINAL
R--1.00, UTS-287.000 - 291.000
SCF-1.0, TEMP-80.0
MAXIMUM STRESS, S_{max}, ksi
300.0
250.0
200.0
150.0
100.0
50.0
10^2
10^3
10^4
10^5
10^6
10^7
FATIGUE LIFE, N, cycles

Battelle

DATA REQUIREMENTS

PHYSICAL PROPERTIES

- CHEMICAL COMPOSITION
- ELASTIC CONSTANTS
- DENSITY
- THERMAL PROPERTIES
- HARDNESS

PRODUCT FORMS

- WROUGHT
- CAST
- P/M
- RST

FABRICABILITY

- MACHINING
- FORMING
- WELDING
- TEMPERING
- COATINGS
- PLATING
- SURFACE TREATMENTS

DATA REQUIREMENTS (CONTINUED)

MECHANICAL PROPERTIES

- TENSILE
- COMPRESSIVE
- BENDING
- TORSION
- IMPACT
- CREEP
- STRESS RELAXATION
- FRACTURE
- FATIGUE
- CRACK PROPAGATION
- BEARING
- SHEAR
- MULTIAXIAL

SERVICE ENVIRONMENT

- MEDIA COMPOSITION
- TEMPERATURE
- LENGTH OF EXPOSURE
- PRESSURE
- PARTICULATES
- VELOCITY

CORROSION RESISTANCE

- BASE MATERIAL
- SURFACE TREATMENTS
- STRESS-CORROSION SUSCEPTIBILITY
- LOAD INTERACTIONS

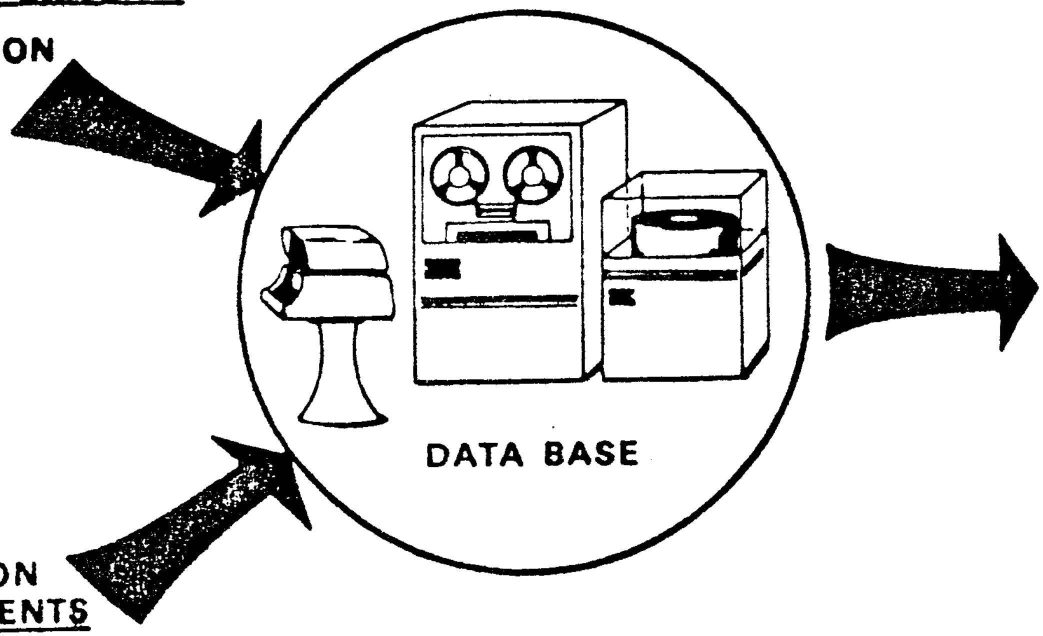
SUBSTITUTION

SELECTION CRITERIA

COMPOSITION
JOINING
FORMING

APPLICATION REQUIREMENTS

STRENGTH
CORROSION RESISTANCE
FATIGUE
ENVIRONMENT



MATERIALS

COMPOSITION
PRODUCT FORM

MATERIALS/PROCESSES

HIP
COATING
P/M
LASER
SURFACES

CAD—MINIMUM WEIGHT
INCREASED LIFE

MATERIAL SOURCES

Battelle
Columbus Laboratories

INFORMATION AS AN ESSENTIAL ASPECT OF CONSERVATION

H. David Chafe
American Society for Metals

INFORMATION AS AN ESSENTIAL ASPECT OF CONSERVATION

H. David Chafe
Director, Metals Information
American Society for Metals

H. David Chafe

Title: Information as an Essential Aspect of Conservation

It is gratifying, and I am tempted to add 'at this late date', to find a recognition of the importance of information ... or perhaps information science and its present-day capabilities ... in the context of a national emergency, and it is encouraging that we have this session on information included in the workshop.

The problem of unavailability or shortage of strategic materials is to some degree addressable in terms of stockpiles of those materials, but this can at best be a temporary measure. Conservation and substitution, by whatever means, offer longer term solutions and effective use of the lead time available for these solutions will be found in a number of presently available and forthcoming information resources.

'Lead time', as mentioned, implies that action must be taken in advance of an emergency. Repeated experience, and this is direct experience in metals information, brings home the fact that information sources, traditionally, seem to be consulted when all else fails. In the jargon, current awareness searching is used very seldom in comparison with retrospective information searching and the lesson is clear ... 'keeping up' or 'keeping ahead' is not yet viewed as the prerequisite; we are still in the mode of reacting to 'what went wrong?'

This workshop, I must hasten to add, is a strong indication that the value of information science may be at a turning point. We, as individuals and representatives of organizations concerned with materials availability, are fortunate that one crisis in advanced, or

advancing, technology is concurrent with another advanced technology that can supply many of the answers.

No one today questions the capabilities of computers; we can assume that there is a machine to do what's needed. The questions are, again

What's needed?, and
What's available?

To a surprising degree, what is needed is available and there are indications that what is needed and not yet available is forthcoming. The remaining and persistent problem will be awareness. In relation to this, I would like to address the two fundamental types of computerized information resource which we have working for us in this country. These are:

Bibliographic files, and
Numeric data files

sometimes differentiated by database and data bank, in turn.

I have used the term "information resource" and, since it fills my purpose so well, would like to show you the dictionary definition.

> Resource, n. 1. something that lies ready for use or can be drawn upon for aid; supply of something to take care of a need.
> 2. usually in pl. something that a country, state,

etc. has and can use to its advantage.

3. a means of accomplishing something; measure or action that can be resorted to, as in an emergency; expedient: as, his only remaining resource.

4. ability to deal promptly and effectively with problems, difficulties, etc.;

SYN. - resource applies to anything, person, action, etc. to which one turns for aid in time of need or emergency.

Considering these types of resource, bibliographic and numeric, in turn:

Bibliographic Databases: Figures compiled by the National Federation of Abstracting Services for 1980 show that the member and affiliate organizations of the Federation, 45 in number, generated abstracts and indexes for nearly two and a half million published papers. In the organizations dealing with technical papers having greater or lesser bearing on materials, 15 of these organizations handled a total of 1,417,200 papers. While recognizing but not documenting some overlap in coverage, the number will still be impressive, and more impressive still is the fact that these document surrogates were substantially all entered into computerized bibliographic databases. For the most part, abstracts journals are now photocomposed, and a counterpart computer tape is a standard by-product of the typesetting operation, along with the typeset pages.

The primary factor in this proliferation of databases, of course, is the emergence of the telecommunications network coupled with the

simplicity of telephone/terminal/computer access. The Lockheed DIALOG System, operating from Palo Alto, CA, and with essentially worldwide access to its computers in that location, currently provides 110 databases online (in widely varying fields), servicing many thousands of terminals and available at least 8 hours a day in most countries.

To provide an example, perhaps I might be forgiven for taking metals as central to materials. Metals Information, with its offices in Metals Park, Ohio (at ASM) and in London, England (at The Metals Society), currently monitors over 1200 technical journals, in addition to comprehensive coverage of conference papers, technical books and dissertations, and selective coverage of patents and government reports. This is done as the initial stage of the publication of Metals Abstracts and its related indexes. Its computerized offshoot, the METADEX database, has been building for sixteen years and now contains bibliographic records of approximately 450,000 documents. Approximately 38,000 document surrogates in the form of abstracts and indexes entered the file last year. At the present time, nearly 800 terminals worldwide access this database each month for an aggregate connect time amounting to over three hundred hours. In all, perhaps 2000 separate locations access this one database occasionally or consistently.

Now, going on to

Numeric Data Banks: While the software for manipulating and locating numerical data online is necessarily different from bibliographic software, the telecommunications network capability is in place and can serve either purpose equally well.

Access to either numerical <u>or</u> bibliographic information, of course, is a model of simplicity with telephone dial-up direct to the computer through local nodes of the network. This avoids extensive long-distance 'phone bills and for the most part the major online services require no up-front charges; costs are based on access time and units of information printed out.

Training in use of numeric databases will necessarily be more demanding than with bibliographic files. In the latter, while the subject matter may differ considerably, the basic SELECT/EXPAND/COMBINE/DISPLAY orders are generally the same file-to-file and system-to-system; Boolean algebra is the working tool in almost all cases, combining some terms and excluding others.

Because of the relative complexity of numerical files, a generalized training approach will not work as easily across data banks, and subject knowledge will have to be a stronger prerequisite. In other words, numerical data banks will probably be the catalyst in producing the next generation of information searcher, and the source of the next (to use an overworked expression) "information explosion". This growth will be demonstrated, and already is appearing, with the search terminal that you will see on the desk of the individual engineer or scientist, rather than (as now) being restricted to the library or information center, with a third party as interface. Equipment costs for terminals, modems, printers and the like have dropped steadily, to the point where purchase is perhaps more likely than lease, and only access costs will be of financial concern. The multiplication of terminals at this point will probably work towards reducing these access fee rates.

Within the next five years, I believe we will begin to see this kind of synergy, with widespread, easy access, at reasonable cost and in the first person ... the kind of access previously available only through handbooks and exhaustive library time, but with the advantages of computer-based recall, scope and speed.

The across-the-board scope of the METADEX bibliographic database, covering all metals and both physical and extractive metallurgy, has governed our thinking in relation to numerical data banks. Most, if not all, of the existing data banks have considerable depth of data over a fairly narrow band of materials. We have been concerned with the need for a broadly-based file, answering the majority of questions such as we receive daily by telephone and letter, and dealing with all types of alloys.

We have now found the basis for this file in the machine-readable counterpart of two recent ASM publications which were designed to provide a correlation for nonferrous alloy and steels designations to the worldwide specifications covering these alloys. Composition and mechanical property values were included for many thousands of materials from twenty countries. The publications are: Worldwide Guide to Equivalent Irons and Steels and Worldwide Guide to Equivalent Nonferrous Alloys.

Computer-based access to such compilations can and does offer substantial advantages over the traditional indexing of the sort found in handbooks. The standard publication indexes to the Worldwide Guides addressed the alloy designation and specification number only. In the

computer file, any element of the information may be requested singly, or combined with any others, or indeed may operate with specific exclusion of certain data elements.

Additionally, computer operation of such a file can utilize number searching (which, of course, can also be done for fixed numbers in a free text bibliographic search) but can also go beyond this to searching ranges of numbers. In other words, a search for steels with 0.06-0.10 C will specify the range and will also pick up steels containing 0.07 C, 0.08 C etc. Beyond this, a second level of ranges is usable in the property field, so that values of composition and (for example) tensile strength required can be asked for together or singly.

It is obvious, of course, that the machine-readable content of two books, extensive though they may be, is only a starting point. Where the books leave off, there must be some means of providing continuous updating, not only for the inclusion of more alloy designations and their related property data, but also for the alteration and editing of existing alloy representations. The latter aspect must include the capability for increasing the number of properties and the inclusion of more than one estimation for a given value.

Metals Information is in a unique position to provide this continuing updating, in terms of source material. The first of these will draw on the editorial operations of ASM's Reference Publications department who will continue to update the Worldwide Guides, and will coordinate any and all other data collection operations in their publications program through machine-readable means.

Our other updating mechanism will draw from the so called "open literature". In the production of Metals Abstracts each year, the U.S. and U.K. offices regularly scan over 1200 technical journals, and they utilize every available method in obtaining the worldwide conference papers, technical books, plus dissertations, patents, government reports, pamphlets and the like. This results in a process of narrowing down from the hundreds of thousands of papers in these sources, to, as last year, the selection of 38,000 technical papers suitable for inclusion in Metals Abstracts and the METADEX database.

A further reduction then occurs in the selection of those papers appropriate for use in a sister publication to Metals Abstracts called Alloys Index. This publication is based on those papers which specify individual alloys (whether designated by an alphanumeric, as a trade name, or compositionally). We find that approximately one-quarter to one-third of the papers going into Metals Abstracts have reference to the alloys, metallurgical systems and intermetallic compounds such as are indexed in Alloys Index. This would mean that perhaps 8-10,000 papers per year are candidates, and the really applicable subset can be determined readily in the existing editorial procedures.

Editing and updating procedures for the numerical database will utilize the present input equipment which connects Metals Park online to the computer center at a distance of twelve miles away for the production of Metals Abstracts. Records may be called up on-screen to display current status, and deletions, changes or additions may be made instantly. The record input will be entered complete with typsetting codes, in order that publications may be drawn from the data bank at any time, and with the content designed as needed.

We are currently agreeing on a contractual arrangement with a major online network to make the data bank available worldwide within a few months. Update input specifications are also being completed, and production updating will commence within the next two months.

All the foregoing having been said, it is realized that this undertaking is not designed for everybody's requirements, especially in the need for the most immediate experimental data, with multiple representations of datapoints and such refinements as extrapolations, curve fitting, or computer graphics. It will, however, grow rapidly into a widely available resource with potential for rapid lookup of information that would be expensive, time-consuming or impossible to find by traditional methods. As time goes on and the rate of addition of alloy representations to the file necessarily dwindles, greater depth of information, such as wear or corrosion characteristics, or thermal properties, for example, may be added to the individual alloy records.

A further possibility is the potential for cross-referencing to the bibliographic records in METADEX, so that the source paper for the recorded values may be consulted.

To return to the basic problem that we are addressing, it is interesting to review some of the subject matter being discussed throughout this meeting, in relation to conservation of strategic materials. There are papers dealing with such subjects as:

Reduction of Cobalt in Gas Turbine Engines

Substitutions for Chromium in Spring Steels (and similarly in Magnetic Alloys, or in High Speed Steels)

Potentials for Claddings/Coatings to Conserve Critical Metals

Conservation of Critical Metals by Surface Alloying

Alternate Methods for Improved Performance (as with Rapid Solidification)

The two types of database I have outlined can and do address all of these problem areas, can locate prior experience, and can, at the very least, speed up our reaction time in an emergency situation. And as we react, or as the situation should develop, it will be all the more important that rapid dissemination of the answers be pursued by all available means.

To quote Dr. Y. S. Touloukian, Director of the Center for Information and Numerical Data Analysis and Synthesis, otherwise known as CINDAS:

> " ... we must realize that our (national and corporate) technological advantages are of little benefit unless they are put to practical use within a relatively short time lapse. At the National level, perhaps the most self-defeating aspect of information usage is the unnecessary delays in its application to our technology. At times we observe that our adversaries and friends alike seem to be able to deploy U.S. technology more rapidly than the U.S. does."

While we recognize some unfortunate truth in this, it is encouraging to come upon a further quote, this time from the Chairman of the House Science Subcommittee who recently referred to

> "the profound impacts of the Information Revolution on our economic prosperity, our national security, and our social and political institutions."

It is very fortunate that, to a large extent, industry will be in a position to, as the quotation said, deploy U.S. technology <u>and a great deal more of the world's technology</u>, if proper use is made of the existing U.S. lead in information techniques and resources.

FACTORS INFLUENCING A NATIONAL MATERIALS SUBSTITUTION INFORMATION DATA BASE

Maurice A. H. Howes
ITT Research Institute

Contribution to
WORKSHOP ON CONSERVATION AND SUBSTITUTION
TECHNOLOGY FOR CRITICAL MATERIALS
Vanderbilt University
Nashville, Tennessee
15-17 June 1981

FACTORS INFLUENCING A NATIONAL MATERIALS SUBSTITUTION INFORMATION DATA BASE

Maurice A. H. Howes
IIT Research Institute
Chicago, Illinois 60616

There are many fragmented data bases available containing information about material substitution which could be integrated to provide data concerning potential substitutions. This is perfectly possible but, if done, would ignore some of the more important aspects of substitution. To make this point clear, the factors influencing the material substitutional data base will be considered.

There are two main potential users of a substitution information data base:

1) Policy maker
2) Designers and engineers

Each requires a different type of information to serve distinctly different needs within the same framework of material needs and supplies.

Policy makers tend to talk about material substitution as if the alternate material can directly replace the original material. In some instances this, of course, is possible, but for most applications a change in material requires a redesign of the product. This design-material interaction is a major factor to be considered in evaluating a material substitution data base.

The policy maker needs information to help decide what substitutions are needed in the national interest. For this activity he needs

1) Information on current resources and reserves of material held in both the public and the private sector.

2) Materials requirements to meet a mix of products nationwide. The mechanism for deciding what the mix should be is outside the scope of this discussion but is of vital importance to the material substitution policy maker.

3) Sufficient information to forecast supplies of material, the demand by industry and government, and the price of materials. Economics cannot be ignored when considering substitutions. Price elasticity of critical materials should be correlated with potential supplies.

An engineer or designer needs different information from a national materials data base:

1) The data base should give complete information on the properties of materials. This is largely available, but there are many gaps in the data. It should also be recognized that there are two sets of material properties, the first being the properties of the material

that affect component performance such as strength, hardness, fatigue resistance, corrosion resistance, etc., and the other being material properties that affect manufacture of the product such as machinability, hardenability, weldability, formability, etc.

2) The choices of alternate materials that are available in a particular national emergency. This information will be developed jointly in coordination with the policy maker.

3) Fabrication methods available for respective substitute materials and the implication on manufacturing processes.

However, a designer or engineer working at an individual company needs far more information than this, much of it specific to his own company operations.

1) The requirements of the product are the first consideration. This includes an analysis of what the component or assembly is actually supposed to do and should not involve design at this stage. Once the essential function and requirements of the component are decided, then the first elements of design can be attempted.

2) There are usually many acceptable permutations of design, materials, and manufacturing methods

that will solve the problem and meet the requirements, but only one will optimize the lowest initial cost. Probably a different combination will optimize lowest life cycle cost and yet another combination will optimize least use of strategic materials. The design will probably alter according to which material is being conserved. Some designs depend on the availability of specific classes of materials. If it were required to build a jet engine without cobalt or chromium being used, it might mean that the engine would have to run at a lower temperature and thus be less efficient and therefore larger as would the airframe need to be to contain it. Thus, the impact of a change in one component may be felt throughout the entire product. The same design considerations have to be given to all components within a total assembly, and so the tradeoffs become extremely complex, probably needing CAD-CAM methodology far more advanced than that available today.

3) A final consideration is what a manufacturing company is able to perform itself. Just because a material selection system suggests a

way of manufacturing a part does not necessarily mean that a company would be able to do so. The company may not have the capacity available to increase the use of any specific manufacturing method or may not even use it at all. Then the decision has to be made between increasing capacity, subcontracting, or using another apparently less optimum method of manufacturing.

In conclusion, the problems of setting up a data base to cover materials alone are immense but, with logical steps, surmountable. However, such a data base will be of limited use unless manufacturing processes and design/material interactions are considered. CAD-CAM techniques can be applied to optimize a design to whatever parameter is believed to be most important at the time of consideration, be it cost or minimum usage of a strategic material or the maximum use of a nationally available manufacturing capability.

The U.S.A. is highly vulnerable to material shortages that are beyond its control, and it is critical that strategies be developed for such crises. A national material substitution data base as described above could be of substantial value to policy makers and to engineers and designers. Development of such a data base would be a major undertaking, but without such a starting point, national response to material shortages would be panic with little available guidance. Stockpiling of critical materials

has long been considered. However, it is even more important to stockpile the information needed on how to use alternate materials. It is very important that action be taken now to establish a Material Substitution Information Data Bank.

INFORMATION REQUIREMENTS WHEN FACED WITH A MATERIAL SHORTAGE

Bruce E. Boardman
Deere & Company

INFORMATION REQUIREMENTS WHEN FACED WITH A MATERIAL SHORTAGE

B.E.BOARDMAN

INTRODUCTION

During the last two and a half days we have heard many talks which approach the problem of dealing with a material shortage. Most have dealt with the problem from only one of many ways. This is not wrong since each may have only one "solution". What I would like to do in the next few minutes is to explore the range of "solutions" which need to be considered prior to the selection of which is appropriate in any one case.

I should point out that in the ground vehicle industry the problem may generally fall into the simple cases but the logic used to determine the path to follow should not change.

FACTORS TO CONSIDER (IN REVERSE ORDER)

In this first section I wish to deal with three areas which need to always be considered: The range of options which may be taken, The scope of the problem, The purpose of the "problem" material. Note that the order within which these items need to be considered is exactly reverse from which I will present.

Range Of Options Which May Be Taken

The range of options which may be taken span the entire possibilities from the easy to the difficult. The choice of which to consider will be dependent upon the reasons for a substitution of material and/or process and the economics envolved. The purpose of the material and the scope of the problem must have already been determined.

Change Chemistry For Equivalent Response

The simplest and generally the most economic action is to change one alloy for another. In order for this to be effective, and the rational, is the premise that the two elements are equivalent. We have heard several talks where hardenability was the primary need to consider and in these cases alloy substitution will be the easiest and least cost method. Along those same lines, the substitution of different grain refiners will effect least cost solutions to material shortages. We could include with that the use of other elements besides magnesium in the production of nodular iron.

Enhance Performance Of Lesser Material

This may be accomplished by mechanical processing, thermal processing, or both. The net result is to produce a material which is equivalent to the predecessor while eliminating the use of a critical element. The use of high strength low alloy

steels is an example of this as is the normal heat treating of parts. Although heat treating is considered normal activity there will be parts where, for economic reasons, alloy materials are used while similar parts could be made from heat treated non-alloy or low-alloy materials.

Reduce Requirements Through Redesign

Frequently a simple redesign will be able to correct a condition which reduces the requirements on a part to a level which will allow a lesser material to perform satisfactorily. This is not to imply that the resultant part is less adequate, only that due to the design change the performance is equivalent. As example were the grain refiners found in the formable grades of steel to become unavailable it could be that changes in bend radius would allow other less formable materials to be used successfully.

Base Alloy Substitution

When it is the base alloy or an alloy which comprises a major portion of the material which is in short supply significantly more effort may be required in order to provide an equivalent part. With major alloy changes the first trial will be for a similar alloy with similar properties. Unfortunately this will only be satisfactory in a small number of cases. The alloys which were chosen originally were generally chosen for special attributes which were otherwise not available. Such things as creep resistance, strength at elevated temperature, electrical or thermal conductivity, and corrosion resistance frequently required very special materials with special properties. Substitution will not be easy or straightforward

Total Function Redesign

The redesign of a system may be the last recorse when the material shortage is so extreme that there are no other material or processing options. This will be the most expensive and time consuming method to satisfying the problem but this method must be kept open. Within this scope of redesign is meant those drastic changes which result in the function of the entire system being performed in a different way.

Scope Of The Problem

As part of the problem and therefore of the solution is the scope of the shortage problem. The expected duration and economic penalities associated with not changing need to be considered. There are four causes for a shortage which come to mind as the primary reasons and each could dictate a different path depending on which one was the cause. The first two relate to the economics of the material and are therefore controlable and action is optional. The later two are not predictable or

controlable and are the more serious of the problems faced by materials engineers.

Supply Exhausted

A completely exhausted supply of a material is the most extreme condition with which we must deal. Fortunately there will be warning signs which were observed and heeded prior to the actual last bit being consumed. These warnings would have allowed time to plan and adjust the subject parts and functions well in advance of the final moment. Frequently the planning for a material's demise could last over several years so that the impact would only be felt by those who were not listening. In the last several years the cost of the material should skyrocket therefore driving the holdouts away for economic reasons.

Economics Of Obtaining

As a material nears its end the cost will increase. This does not mean that a user must stop using the material, only that the cost of the final product will increase. It is likely that cost will finally drive the product off the market prior to the total depletion of material.

Temporary Shortage

The temporary shortage is a nasty condition since it is normally unpredictable and occurs without warning. One difficulty is that the temporary solution may be very little different from the solution were the supply totally exhausted but without the time to react. Changes made frequently will not be reversible.

Politicially Created Artifical Shortage

The politicially created shortage is artifical. It may range from no supply available to a supply but at an inflated price. There will be no clear cut route to take since the condition may change back and forth at any time.

Purpose Of "problem" Material

The final area to discuss which is also the first area to consider when faced with a material shortage is a critical answer to the question "What is the purpose of this material?"

Base Material

Is this shortage with the base material without which the design cannot be made. If so the materials engineer will be in a deep hole. Is there another material which is similar enough to satisfy the requirements with only minor change in design or cost.

Primary Alloy

Shortage of an alloy which is primarilly responsible for the behavior of the part. As above then another similar material may be considered.

Secondary Alloy

There is a lesser problem if the shortage is in one of several alloys which together produce and effect. Most frequently this is the condition with hardenability and other common steel alloys. This option may not be available for the superalloys common to the high temperature jet engine, gasification, or nuclear industries.

INFORMATION REQUIREMENTS

Effect Of Alloy

Mechanical Properties

Response To Thermal/Mechanical Processing

Cost and Current Availability Of Substitutes

Future Projected Cost And Availability

ACCESS REQUIREMENTS

Ways To Explore Options

Online Data Access

Ways To Reduce Trivial Or Non-Essential Information

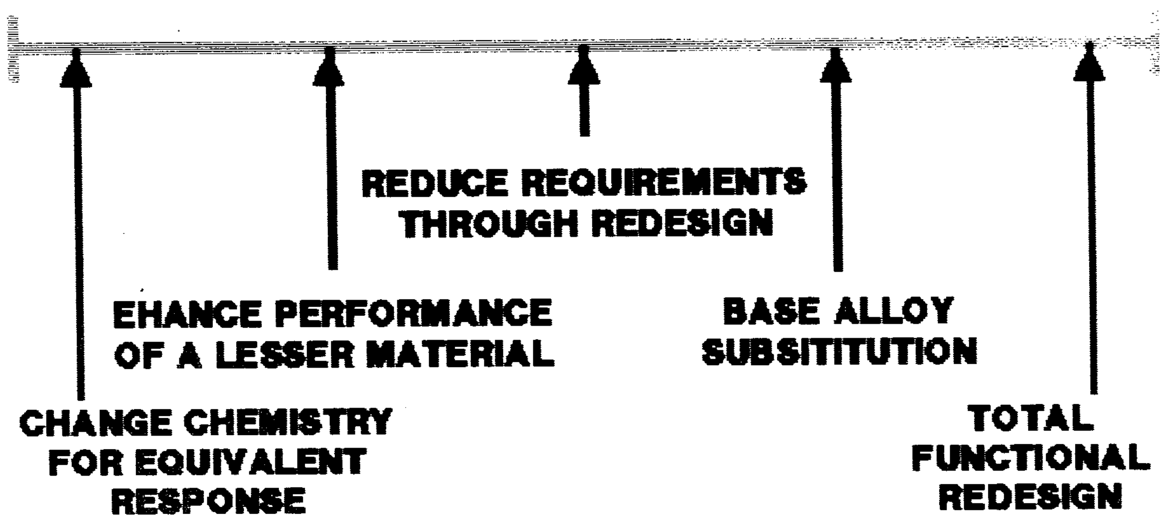
All Previously Discussed Information

BEB1.INP

FACTORS TO CONSIDER WHEN FACED WITH A MATERIAL SHORTAGE

- RANGE OF OPTIONS
- SCOPE OF PROBLEM
- PURPOSE OF MATERIAL

RANGE OF OPTIONS WHEN REACTING TO A MATERIAL SHORTAGE



OSS>

BEB2.INP

SCOPE OF PROBLEM

- SUPPLY EXHAUSTED
- ECONOMICS OF OBTAINING
- TEMPORARY SHORTAGE
- POLITICALLY CREATED

BEBS.INP

PURPOSE OF "PROBLEM" MATERIAL

- BASE MATERIAL
- PRIMARY ALLOY
- SECONDARY ALLOY

INFORMATION REQUIREMENTS

- EFFECT OF ALLOY
- MECHANICAL PROPERTIES
- RESPONSE TO THERMAL/ MECHANICAL PROCESSING
- COST AND CURRENT AVAILABILITY OF SUBSTITUTES
- FUTURE COST AND AVAILABILITY

INFORMATIONAL REQUIREMENTS

MECHANICAL PROPERTIES
THERMAL/MECHANICAL RESPONSE

	CHEMISTRY	MECHANICAL PROPERTIES	THERMAL MECHANICAL LOAD HISTORY
SECONDARY ALLOY FOR EQUIVALENT RESPONSE	⬢		
THERMAL MECHANICAL PROCESSING	⬢	⬢	
REDESIGN TO REDUCE MATERIAL REQUIREMENTS	⬢	⬢	⬢
BASE MATERIAL OR PRIMARY ALLOY	⬢	⬢	⬢
REDESIGN FUNCTION	⬢	⬢	⬢

BEB5.INP

ACCESS REQUIREMENTS

- WAYS TO EXPLORE OPTIONS
- ON-LINE DATA ACCESS
- WAYS TO REDUCE NON-ESSENTIAL INFORMATION
- ALL PREVIOUSLY DISCUSSED INFORMATION

SUBSTITUTION PREPAREDNESS-
THE INFORMATION STOCKPILE ON SUBSTITUTION TECHNOLOGY

John Rumble
National Bureau of Standards

COMMENTS ON

"SUBSTITUTION PREPAREDNESS -

THE INFORMATION STOCKPILE ON SUBSTITUTION TECHNOLOGY"

Given by

John Rumble
Office of Standard Reference Data
National Bureau of Standards
Washington, D.C. 20234

at the Workshop on Conservation and Substitution

Technology for Critical Materials

June 17, 1981

Vanderbilt University
Nashville, Tennessee

I would like to thank Alan Gray of ASM for inviting me to talk here today. Certainly the sessions held during the past two-and-a-half days have highlighted the problems for both our national economic well-being and our national security of our present day dependence on materials either in short supply or from foreign sources. The past two-and-a-half days have also focused on ways of implementing the four strategies to reduce these dependencies, namely, by substitution with materials of equal or better properties and performance, by displacement with materials with lesser properties but about equal performance, by conservation of materials by new processing and fabrication technologies, and by recycling of these materials after use.

Today, we are focusing on what has been called the "Information Stockpile" required to implement these strategies. In my talk (outlined in figure 1), I want to discuss four aspects of these data needs which I firmly believe play a fundamental role in providing a framework for building such an information stockpile. The first will be a review of the fources which have changed in the past few years to allow us to consider actually making such a stockpile now. The second will outline the different types of data involved and their relationship to the motivating forces described previously. The third will address the different needs of the private and public sector for materials information. The last will be concerned with the need for evaluation as a critical component for several key types of data. After this, I will briefly describe the NBS materials sciences data programs and outline the role they might play for information on critical materials.

The underlying basis for this entire discussion needs to be clearly stated from the beginning. The task of creating all, or even a significant part, of an information stockpile on critical materials is large, complex, and impossible for any one organization or activity to complete. The considerations which I describe will hopefully allow the diverse data activities, present and future, to maintain a clear perspective, both of what they can and should do and of what others can do, recognizing the limited resources available.

Why Now?

The data needs of many parts of the materials community have been the subject of several studies in the past decade, some of which are shown in figure 2. Not remarkably, these needs have not changed appreciably, even for those specific data needs directly relating to relieving dependence on critical materials. This is not remarkable because the basic problems of expense, availability, and performance have been with the materials community from earliest times. But two important factors have changed recently (figure 3), namely, the ability to understand and predict material properties and performance and the ability to accumulate and distribute the resulting knowledge. The first of these has played a primary part in the discussions of the past two days as evidenced by the new technologies and materials talked about. The second is a reflection of the computer revolution, the impact of which is still growing by leaps and bounds. Quite simply, we can generate better data and can make it available more easily.

Let me demonstrate these new capabilities by posing a materials design question in two entirely different ways (figure 4). Upon reflection, each of the questions is even more complex than is obvious at first glance. Everyone in the materials community wants to combine economic data, processing technology data, basic scientific and technical data, and performance data in one way or another. From our own experience, we all realize how difficult it has been to have access to and to use the handbooks, cost sheets, and manufacturer's specifications for these data. I am not suggesting that an all-encompassing data base which instantly answers these questions can be built, even within our lifetime. That will be discussed more later. But if we refer back to the four strategies to reduce our dependence on critical materials--substitution, displacement, conservation, and recycling--we can imagine that individual data bases will soon exist which should be able to answer quickly parts of similar questions which arise from pursuing each of these strategies. Why is now the time for creating the data resource on substitution technology? Because more and better data are available and because computers will allow us easily to get at these data.

Types of Data

The use of a particular material in a given product requires many considerations: cost, weight, performance, reliability of supply, ease of fabrication, and numerous others. It is instructive to refer to one version of the materials cycle which also contains the flow of information relevant to each stage of that cycle (figure 5). This particular representation has been adopted from one given in a report on Information Systems Supporting U.S. Materials Policy done by the Office of Technology Assessment for the U.S. Congress in 1976. The information that is shown on this picture can loosely be classified as economic, technical, and political. Some of the actual data falls in two or three of these categories, but let us concentrate on the technical data only, particularly those data needed for substitution analysis and material production for critical materials in figure 6. First and foremost, data are needed to characterize the physical, chemical, mechanical, and performance properties of presently utilized materials containing one or more critical materials. A more detailed list of these properties is given in figure 7 for substitution analysis. Clearly these data are what material and product designers now use, implicitly and/on explicitly, relying on whatever sources with which they have become familiar and comfortable. In addition, formal data activities in many of these areas now exist, mainly sponsored by the Federal Government. It should be pointed out that, without exception, these data centers are all in severe need of more resources.

The next types of data needed are the same physical, chemical, mechanical, and performance properties of alternative materials, those either substituting or displacing substances containing critical materials and those resulting from greater use of recycled, and probably contaminated, materials. Lastly, a more complete list of data needed to aid in designing and implementing new, improved material production technologies is given in figure 8. Such data cover an amazing range of disciplines, from thermodynamic data needed for the roasting of ores to metastable phase data for rapid solidification technology to data used to predict the mechanical properties of components cast into near-net-shapes.

The data needs outlined above are by no means exhaustive, but they lead to what I consider to be the most important conclusion regarding technical data needs. That conclusion is that materials designers and producers need many diverse types of data simultaneously (figure 9). It might be pointed out that this is neither startling or new. But its implications for existing and future data activities are large. Presently, most, if not all, materials-related data work is discipline oriented. The Battelle Metals and Ceramics Information Center;s Mechanical Property Data Center is concerned with mechanical properties. The NBS Alloy Phase Diagram Data Center is concerned with alloy phase data. Purdue's CINDAS Data Center is concerned with thermophysical properties. But to date, even though it is recognized that the need exists for data users, in this case, the materials designers and producers, to access a lot of different data all at once, no data activity has had the resources or charter to do this.

Let me reiterate this last point. If the materials community is going to be serious about development an information stockpile to reduce the U.S.'s dependence on critical materials, then this important need to access simultaneously several different data bases must be fulfilled.

Public and Private Data

With these cross-disciplinary needs well in mind, let us now consider how these needs might be satisfied and in what form. As a preliminary, it should be noted that even though there is an overdependence on critical materials such as that outlined over the past two days, that in itself would not be bad if there were one hundred percent assurance that supply changes would be orderly and not subject to artitrary and unpredictable disruption. But our experience of the last decade makes us believe otherwise.

Because we cannot predict when the problems will arise, two time scales (figure 10) are important for developing the needed data bases and information collections. The first is long-term and is based on the economic principle that a particular materials company can best maintain its long-term competitiveness by gradually incorporating new processes and utilize alternative materials in a systematic fashion over a period of time, such that when the crunch comes, the adverse effects are minimized.

The second time scale is that defined by a disruption, especially an unpredictable disruption. The needs of society met by the materials industry will remain, and the company able to respond just as quickly as it did the day before the disruption will do the best economically.

It is more, however, than just the private sector which has a concern with both of these time scales. Certainly for defense purposes, it is clear that we must on the long-term take the needed steps to relieve gradually our dependence on the critical materials. But even more important, if and when the disruptions do occur, it will likely be a time of increased defense needs, the fulfilling of which could be most important to our survival. We must be able to respond quickly in this situation.

What all does this have to do with the idea of an information stockpile? The answer is that there are two separate data needs, one related to the private sector and economic competition, the other related to legitimate national interests, and they need data for different reasons and at different times. Further, as pointed out earlier, there is a new large effort needed to integrate, in some unspecific way, existing and future discipline-oriented data activity. It is a fact that, to date, most materials data activity available publicly has been federally sponsored. There are some notable exceptions, especially for the publication of handbooks by technical and industrial groups. There is a good reason for this Federal involvement. Most competitive companies in the materials industries have developed, in one form or another, their own internal data sources. These are usually a combination of published data and proprietary data. There is a natural reluctance for these companies to share their data with their competitors. Realistically, within these internal data bases, little of the proprietary technical data is unavailable to others from other sources or is critical to the company's survival, especially on an item-by-item basis. But the value of having collected it and the ease of use by their own technical people can provide a company with a critical competitive edge.

Because of the above considerations and the large cost of any type of information stockpile, it is obvious that activity will be necessary on several different levels and that cooperation between the private and public sectors will be necessary. In particular, the Government will need to continue to support, and in fact increase support for, specialized scientific and technical data activities on a discipline basis. The integration of these and other data bases into a public information stockpile will most likely take place in more than one way and will need the strong backing of individual companies, industrial groups, and the Government. This kind of cooperation has already started to some degree as shown by the recent efforts by the Metal Properties Council and its work on mechanical property data and the joint American Society of Metals/National Bureau of Standards program for evaluation of alloy phase diagrams.

Evaluation of Data

I wish to make a couple of brief but important points concerning the need and role of evaluation in an information stockpile such as is under discussion. It should be evident to everyone who has given thought to building materials data bases that such data bases cannot simply be a blind collection of information. In many respects, the material sciences have less developed methodologies, for characterizing both properties and materials, than say chemistry. In addition, the inherent specimen-dependent nature of some properties gives rise to a real need for the information stockpile builders to examine carefully the included data to insure that the material studied was well characterized and that the material dependence vis-a-vis specimen dependence of a given property has been well documented.

An example is the melting point of a pure metal on different alloy phase diagrams. Obviously, it must be the same regardless of the system. For instance, in a well-known collection of phase diagrams, the melting point of titanium is reported as 1660, 1680, and 1720 C for different titanium alloy systems (figure 11). This example of an almost trivial piece of data suggests how large the problem will be for complex materials and less well-defined properties. Such evaluations can only be done by state-of-the-art materials people.

This means that evaluation will be expensive, but it must be done this way for the data collection to be useful.

The National Bureau of Standards Data Programs

The NBS Office of Standard Reference Data (OSRD) Materials Sciences Data Program is designed to provide needed physical, chemical, and metallurgical data for a better understanding of solid materials and their use (figure 12). Presently the main effort is directed towards compiling, evaluating, and disseminating basic data about phase equilibrium and crystal structure. OSRD helps support four data centers concerned with these data, which are fundamental in characterizing solid materials. In addition, another data center is concerned with transport in solids. Figure 13 gives some information about all of these centers.

Phase equilibrium data are compiled by two separate data centers, one for alloys--the Alloy Phase Diagram Data Center, and one for ceramics--the Phase Diagrams for Ceramists Data Center, both at NBS. The Alloy Center has been working closely with the American Society of Metals to set up and implement a program to evaluate systematically phase diagrams for binary and higher-order alloys. This program will be described in detail below. The Phase Diagrams for Ceramists Data Center has recently been discussing a similar program to be done with the American Ceramics Society. The hope is to increase greatly the coverage and publication frequency of the ceramic phase diagram series. Such a program will undoubtedly enhance access to evaluated non-metallic phase data.

Data on transport in metals, especially mass transport and diffusion phenomena, are the scope of the Diffusion in Metals Data Center at NBS. This data center maintains a comprehensive collection of relevant literature and, for certain substances, performs in-depth evaluations and reviews. The data center is just now finishing a second volume concerning the diffusion of copper in various substances, which work has been jointly sponsored by the International Copper Research Association (INCRA).

Crystalline structural data are the concern of the NBS Crystal Data Center and the Cambridge Crystal Data Centre. Both of the centers maintain computerized files on substances subjected to crystallographic analysis. In the next few months, the NBS Crystal Data Center will begin distributing via an on-line computer network a data base for the identification of crystalline materials using single crystal diffraction data. The data base contains over 60,000 compounds.

In making a list of important materials properties, certainly phase equilibrium data are among the most important. Indeed, to talk intelligently about other properties of a material, it is necessary to be able to specify the stable phase(s) of that substance under the desired conditions. The NBS Alloy Phase Diagram Data Center has started a joint program with the American Society of Metals to provide a systematic effort to evaluate all existing phase data for metal alloy systems. This work will update and supercede the compilations by Hansen and the additions by Elliott and Shunk.

As shown in figure 14, the program has five components. The binary systems and the Bulletin of Alloy Phase Diagrams have already started and will be described in detail below. The higher-order systems program is just beginning to get focused. Because of the greater number of higher-order systems, it is crucial

to identify important types of systems and to coordinate any new evaluation work with existing efforts. Hand-in-hand with the phase diagram evaluation program is the use of computers in disseminating the results as shown by items 4) and 5) in figure 14. Computer graphics research done by the Alloy Data Center has produced software which can generate phase diagrams of publishable quality.

In figure 15, the complete phase diagram for the lead-silver system is shown, and figure 16 demonstrates the ability of the computer graphics program to expand the detail on a particular section, in this case the lead-rich portion. Such a capability is particularly attractive for more complicated diagrams such as in figure 17, that of the mercury-uranium system, where it is difficult to see all the detail in one diagram. Eventually this graphical information will be combined in a public data base with the appropriate thermodynamic, crystallographic, and supporting information, but it will be a while before such a data base is available. This is one example of the integration of discipline-oriented data bases which I mentioned earlier.

The evaluation program for binary allow phase diagrams is well under way. The program is well organized so that for each set of systems there will be a separate editor who will work under the editor-in-chief, Professor Ted Massalski of Carnegie-Mellon. Work is presently under way for several systems, including alloys containing V, Ti, Ag, Zr, Zn, Cd, and Be. Four other systems, Cu, Ni, the alkali metals, and the rare earths will soon be started. The evaluations will not only contain the actual phase diagrams drawings but also will include a thorough discussion of the experimental work, phase structural data, thermodynamic data, and references. Information on metastable phases will be included as available and appropriate. The output will be published both in the Bulletin of Alloy Phase Diagrams and as monographs.

As International Council on Alloy Phase Diagrams exists, and the members contribute to the NBS/ASM program, both as individuals doing evaluations and as members of working committees. The council has played an important role in identifying other evaluation efforts and in helping to set out evaluation criteria.

The power of the program is derived from two separate aspects. The first is the systematic evaluation by recognized experts of phase data for all binary systems. The second is in the phase diagram data bank which will likely be an important component of any information stockpile on critical materials.

One other important part of the NBS/ASM joint program is the publication of the Bulletin of Alloy Phase Diagrams (figure 18). This bulletin is designed to put evaluated phase data in the hands of users quickly and in an easy-to-use manner. The second issue has just been distributed. Among other things, it features computer-generated phase diagrams such as those shown before.

OSRD also supports data programs in many other areas. Some of the ones of particular interest to the materials community include Chemical Thermodynamics, Fluid Transport Properties, Chemical Kinetics, and Molten Salts. Information on any of these programs can be obtained by contacting the Office of Standard Reference Data at NBS.

Summary

In closing, I would like to reemphasize a few points made above. First, the new advances in generating materials data and in computers has allowed us to consider for the first time creating an information stockpile on critical materials. But the effort will be large and expensive and will require close cooperation of the private and public sectors, especially to insure the limited resources available are not used to duplicate work.

COMMENTS ON INFORMATION STOCKPILE

FOR SUBSTITUTION TECHNOLOGY

I. IMPORTANT CONSIDERATIONS

- WHY NOW?
- TYPES OF DATA
- PUBLIC AND PRIVATE DATA
- EVALUATION

II. NBS MATERIALS SCIENCES DATA PROGRAM

Figure 1

PREVIOUS STUDIES ON MATERIALS INFORMATION

(PARTIAL LIST)

1964 DISSEMINATION OF INFORMATION ON MATERIALS, MATERIALS ADVISORY BOARD, NAS

1969 PROCEEDINGS OF NATIONAL ENGINEERING INFORMATION CONFERENCE, OFFICE OF SCIENCE AND TECHNOLOGY AND ENGINEERS JOINT COUNCIL

1970 A SYSTEMATIC EVALUATION OF MATERIALS FOR STRUCTURAL APPLICATION

1972 NATIONAL MATERIALS ADVISORY BOARD, NAS
REPORT ON SURVEY OF MATERIALS-ORIENTED SCIENTIFIC AND TECHNICAL SOCIETIES' INFORMATION SERVICE
FEDERATION OF MATERIALS SOCIETIES

1974 REQUIREMENTS FOR FULFILLING A NATIONAL MATERIALS POLICY, OFFICE OF TECHNOLOGY ASSESSMENT (OTA)
U.S. CONGRESS

1975 FEDERAL MATERIALS RESEARCH AND DEVELOPMENT: MODERNIZING INSTITUTIONS AND MANAGEMENT
GAO

1976 TECHNOLOGY ASSESSMENT OF MATERIALS INFORMATION SYSTEMS
IBM

Figure 2

1976 An Assessment of Information Systems Capabilities
Required to Support U.S. Materials Policy Decisions
OTA, U.S. Congress

1978 National Needs for Critically Evaluated Physical
and Chemical Data
Numerical Data Advisory Board (NDAB), NAS

1980 Mechanical Properties Data for Metals and Alloys
NOAB, NAS

WHY NOW?

- BETTER DATA AVAILABLE
- COMPUTERS ARE BETTER

Figure 3

QUESTIONS

1. HOW CAN WE MANUFACTURE HIGH PERFORMANCE AIRCRAFT ENGINE TURBINE BLADES WITHOUT CHROMIUN ?

2. HOW CAN WE DESIGN A NEW

   HIGH STRENGTH (STEADY STATE CREEP DOWN TO 0.2% IN 8-10,000 HOURS, HIGH TENSILE STRENGTH, DUCTILE, LOW CYCLE AND THERMAL FATIGUE RESISTANT)

   HIGH TEMPERATURE (1200-1600 C)

   CORROSION RESISTANT (MAX 10 MILS IN 10,000 HRS PENETRATION)

   GOOD FABRICABILITY AND WELDABILITY

   LIGHTWEIGHT MATERIAL ?

Figure 4

Basic Informational Framework Applied to Materials Substitution

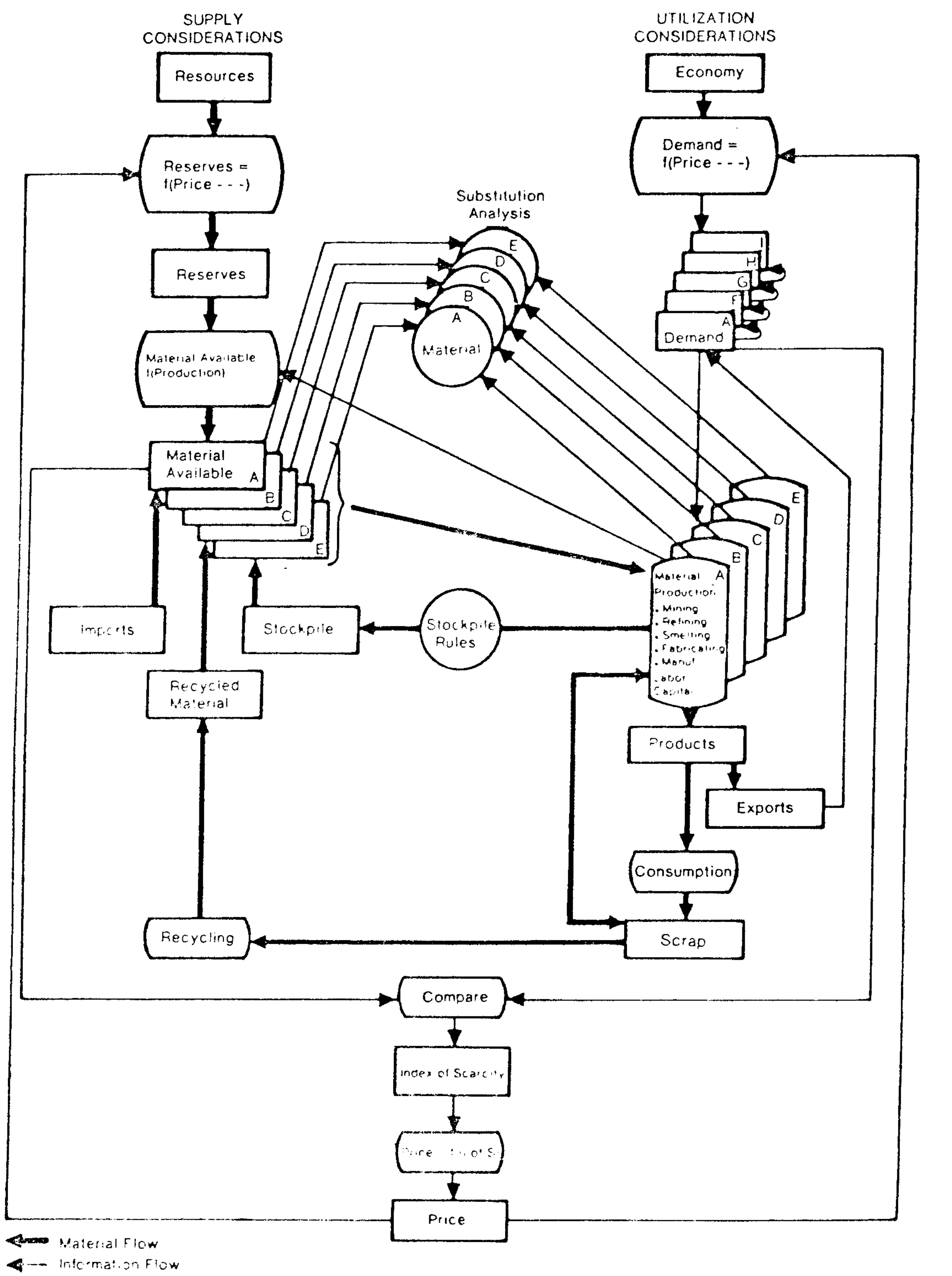


Figure 5

SCIENTIFIC AND TECHNICAL DATA IN THE MATERIALS CYCLE

SUBSTITUTION ANALYSIS

EXISTING MATERIALS
ALTERNATIVE MATERIALS

PHYSICAL
CHEMICAL
MECHANICAL
PERFORMANCE

MATERIAL PRODUCTION

MINING
REFINING
SMELTING
FABRICATION
MANUFACTURING

Figure 6

SUBSTITUTION ANALYSIS

Scientific and Technical Data For Existing and New Materials

Physical Properties

Density
Hardness
Coefficient of Friction
Viscosity
Porosity
Permeability
Reflectivity

Chemical Properties

Corrosion
Reactivity
Solubility
Thermal Stability
Oxidation
Sulfidation
Crazing

Thermal Properties

Conductivity
Specific Heat
Coefficient of Expansion
Melting Point

Mechanical Properties

Tension
- Stress-Strain
- Tensile Properties

Modulus of Elasticity
Compression
Bearing
Shear
Fatigue Strength
Creep
Crack Propagating Resistance
Impact Resistance
Wear Resistance
Stress Corrosion
Cavitation

Electrical Properties

Dielectric Constant
Conductivity

Figure 7

MATERIALS PRODUCTION

MINING

REFINING

SMELTING

FABRICATION

- WELDABILITY
- MACHINABILITY
- HEAT TREATABILITY
- FORMABILITY

FORMING

SHEET	FORGING
PLATE	CASTING
BAR	TUBING
EXTRUSION	POWDER

Figure 8

<u>MATERIALS DESIGNERS AND PRODUCERS NEED ACCESS TO MANY DIVERSE TYPES OF DATA SIMULTANEOUSLY</u>

Figure 9

INFORMATION STOCKPILE ON CRITICAL MATERIALS

PERTINENT TIME SCALES

- LONG TERM - MAINTAINING ECONOMIC COMPETITIVENESS
  - EVALUATING ALTERNATIVE MATERIALS AND PROCESSES

- SHORT TERM - MEETING INCREASED DEMANDS
  - REACTING TO DISRUPTIONS

Figure 10

REPORTED MELTING POINTS OF PURE TITANIUM

ALLOY SYSTEM	M.P. (C)
TI - ZR	1720
TI - ZN	1680
TI - V	1720
TI - U	1660

Figure 11

OSRD MATERIALS SCIENCES DATA PROGRAM

TO PROVIDE NEEDED PHYSICAL, CHEMICAL, AND METALLURGICAL DATA FOR A BETTER UNDERSTANDING OF SOLID MATERIALS AND THEIR USE.

- PHASE EQUILIBRIUM DATA
- TRANSPORT DATA
- STRUCTURAL DATA

Figure 12

OSRD MATERIALS SCIENCES DATA PROGRAM

PHASE EQUILIBRIUM DATA

ALLOY PHASE DIAGRAM DATA CENTER - R. MEHRABIAN, NBS
NBS-ASM JOINT PROGRAM

PHASE DIAGRAMS FOR CERAMISTS - L. COOK, NBS
AMERICAN CERAMIC SOCIETY - NBS JOINT PROGRAM
(IN FORMATION)

TRANSPORT DATA

DIFFUSION IN METALS DATA CENTER - J. MANNING, NBS

STRUCTURAL DATA

CRYSTAL DATA CENTER - A. MIGHELL, NBS
CAMBRIDGE CRYSTAL DATA CENTRE - O. KENNARD, CAMBRIDGE, U.K.

Figure 13

ALLOY PHASE DIAGRAM DATA CENTER

NBS-ASM JOINT PROGRAM FOR PHASE DIAGRAM DATA

1) BINARY ALLOY PHASE DIAGRAMS -

   COMPREHENSIVE COMPILATION AND EVALUATION

   UPDATE AND REPLACE HANSEN, ELLIOTT, AND SHUNK VOLUMES

2) BULLETIN OF ALLOY PHASE DIAGRAMS -

   A PERIODICAL TO PUBLISH "PROVISIONAL" DIAGRAMS FOR RAPID DISTRIBUTION AND USER FEEDBACK

3) TERNARY AND HIGHER-ORDER ALLOY PHASE DIAGRAMS

   COMPILATION AND EVALUATION

   COORDINATION OF CURRENT EFFORTS HERE AND ABROAD

4) COMPUTER PHASE DIAGRAM GRAPHICS

5) COMPUTER DATA BASE OF PHASE STABILITY INFORMATION

Figure 14

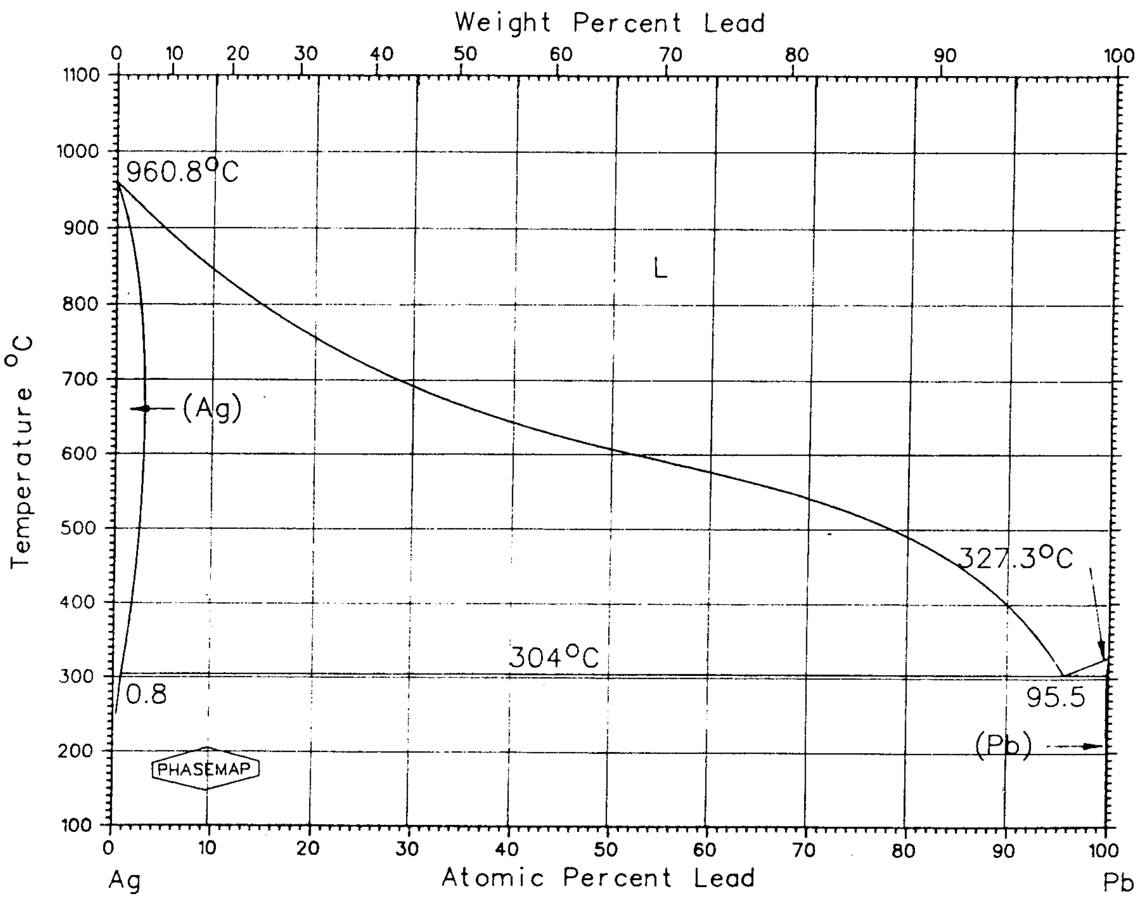
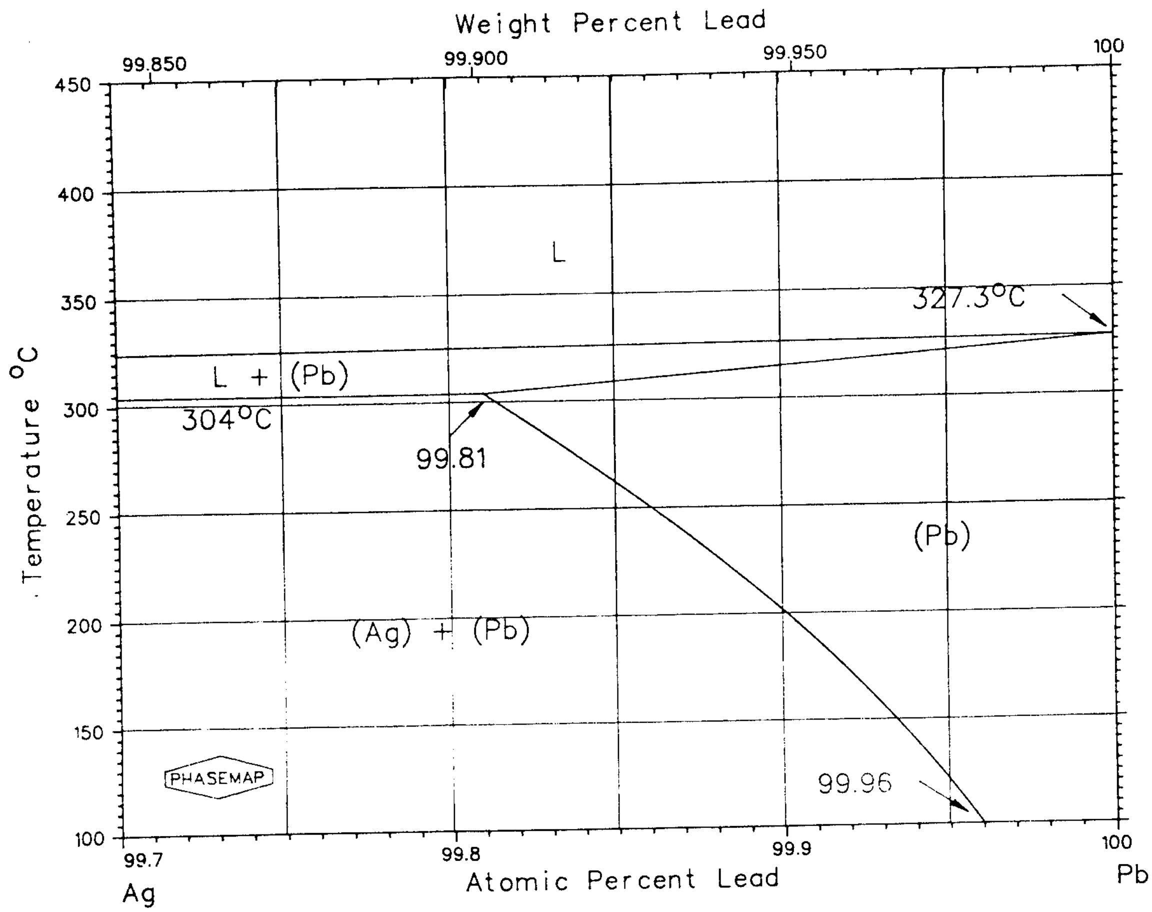

Weight Percent Lead
0
10
20
30
40
50
60
70
80
90
100
1100
1000
900
800
700
600
500
400
300
200
100
Temperature °C
960.8°C
L
(Ag)
327.3°C
304°C
0.8
95.5
(Pb)
PHASEMAP
0
10
20
30
40
50
60
70
80
90
100
Ag
Atomic Percent Lead
Pb

Figure 15



Weight Percent Lead
99.850
99.900
99.950
100
450
400
350
300
250
200
150
100
Temperature °C
L
327.3°C
L + (Pb)
304°C
99.81
(Pb)
(Ag) + (Pb)
PHASEMAP
99.96
99.7
99.8
99.9
100
Atomic Percent Lead
Ag
Pb

Figure 16

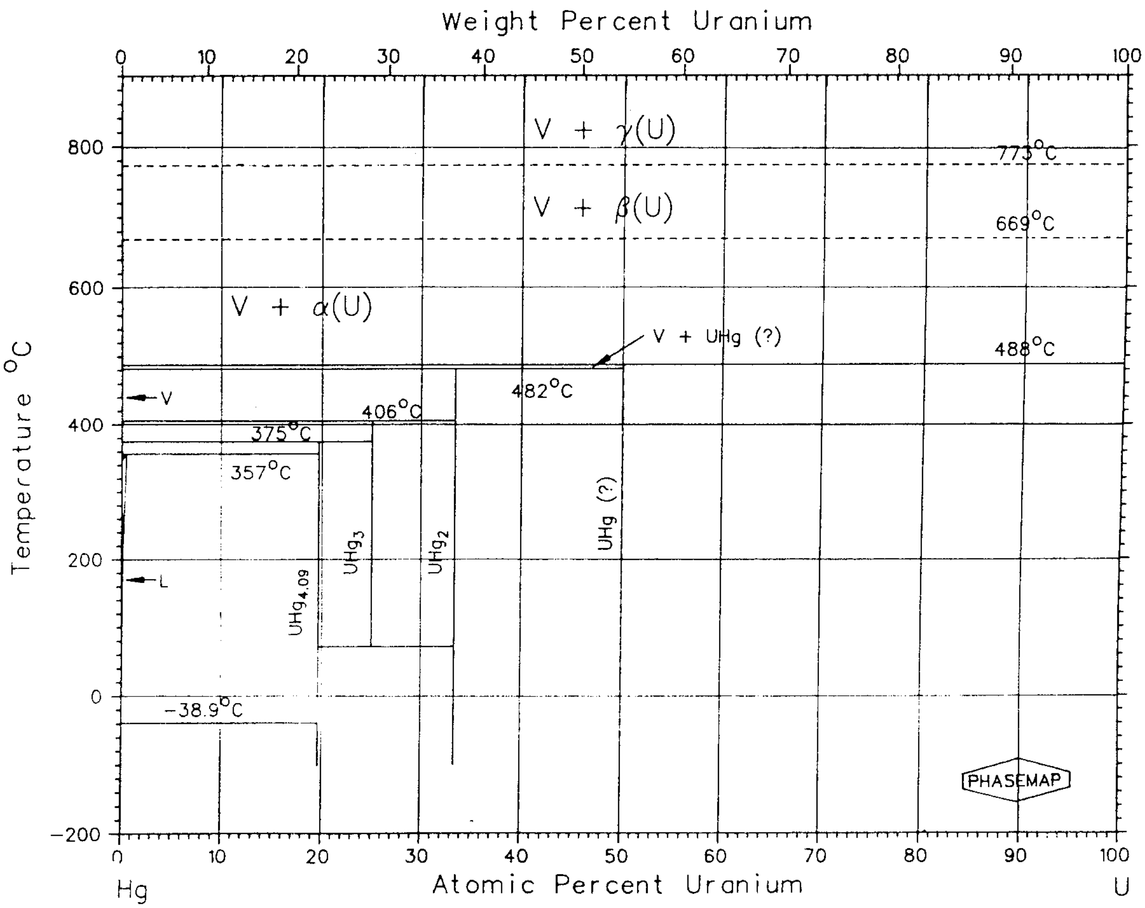
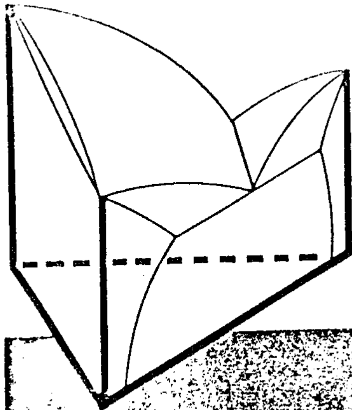

Weight Percent Uranium
0
10
20
30
40
50
60
70
80
90
100
V + γ(U)
773°C
V + β(U)
669°C
V + α(U)
V + UHg (?)
488°C
482°C
406°C
375°C
357°C
-38.9°C
V
L
UHg4.09
UHg3
UHg2
UHg (?)
Temperature °C
800
600
400
200
0
-200
PHASEMAP
Atomic Percent Uranium
Hg
U

Figure 17

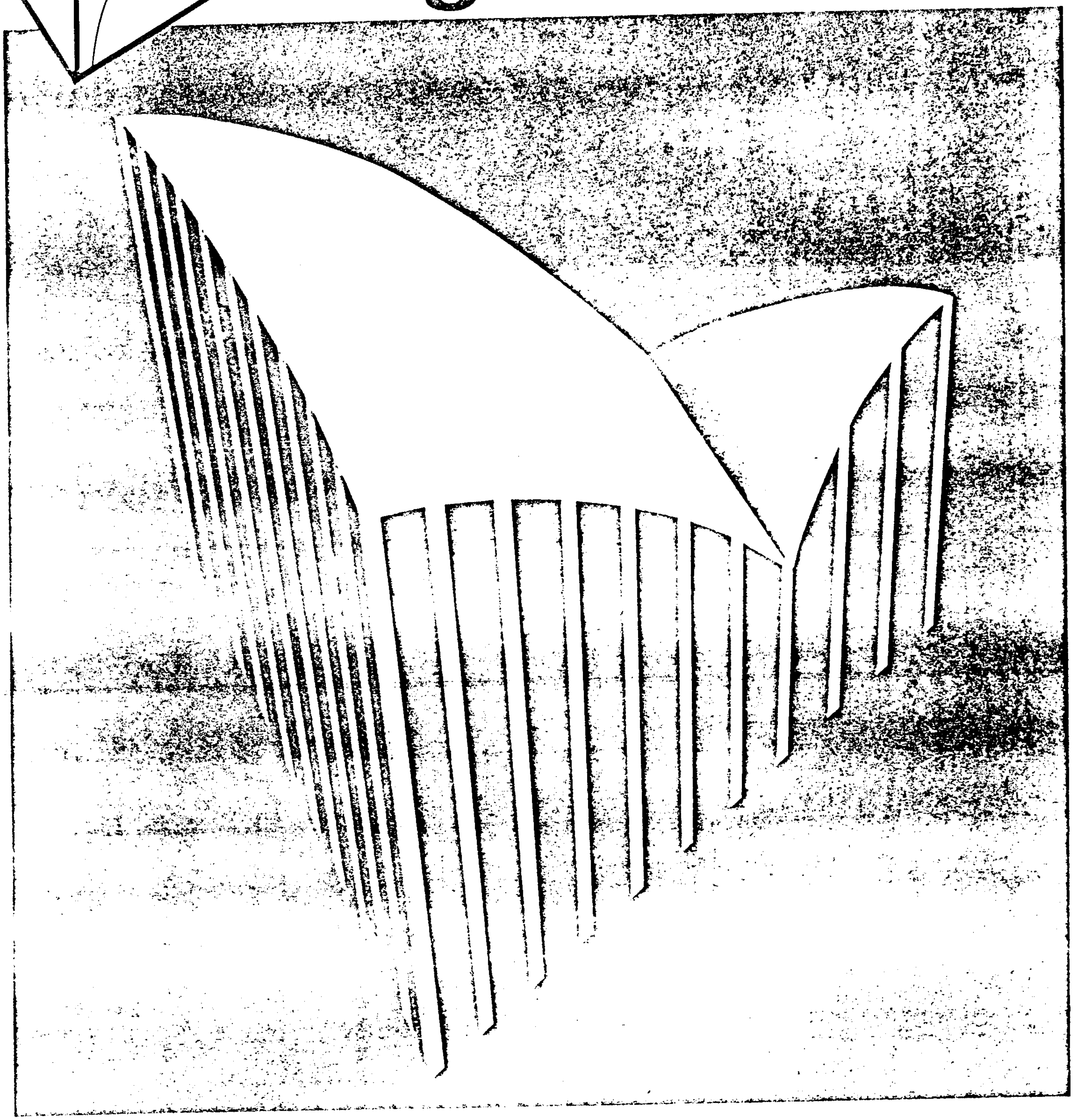
Figure 18



Bulletin of

alloy phase diagrams

Vol. 1 No. 1



published quarterly by American Society for Metals

as part of the American Society for Metals/National Bureau of Standards Data Program for Alloy Phase Diagrams P49-27

REQUIREMENTS FOR AN INFORMATION STOCKPILE ON SUBSTITUTION TECHNOLOGY

Frank M. Richmond

Universal-Cyclops Specialty Steel Div.

CONSERVATION AND SUBSTITUTION TECHNOLOGY
FOR CRITICAL MATERIALS

Vanderbilt University
Nashville, Tennessee
June 15-17, 1981

REQUIREMENTS FOR AN INFORMATION STOCKPILE ON SUBSTITUTION TECHNOLOGY

BY

Frank M. Richmond
Universal-Cyclops Specialty Steel Division
Cyclops Corporation

In preparing for this brief talk on information stockpile requirements, I personally am confronted with a situation somewhat similar to the overall theme of this session. The efficiency of an information stockpile program depends to a large degree on our ability to predict the kind of information that may be required. In my case, the challenge was to predict subjects that may not have been covered by a prior eight speakers in this session and/or one of the many others at one of the previous sessions.

The specific aspects of information stockpile I have selected for discussion are:

a) How do we define a critical material?

b) Alternative domestic raw material sources (other than domestic mines)

c) Basic R & D as an information stockpile

Definition of a Critical Material

The value of a limited information stockpile on critical materials obviously depends in a great degree on our ability to predict what materials may require substitutuon at some point in the future. This problem is analagous to the problem facing DoD and FEMA in attempting to define actual national stockpile requirements. In fact, an information stockpile obviously supplements our materials stockpile; to the extent that the stockpile goals have been properly designed and achieved, the necessity for an information stockpile decreases - at least with respect to a national emergency. We still, of course, are left with the potential need for substitute materials at times other than national emergencies. For instance, the five-fold increase in the price of cobalt between May of 1978 and February 1979 sent alloy designers and materials engineers scurrying to find substitutes for cobalt-containing alloys.

At this stage of the workshop, it is quite possible that a critical material has been defined several times. As a member of several committees on critical materials, I am well aware, however, that there is no universal definition. An excellent effort in this direction is currently being made by Ken Stalker of General Electric, Evendale, who in connection with the Metal Properties Council Task Group on Critical Materials

is attempting to come up with a critical element index for eighteen metallic elements. His approach incorporates ranking each of the eighteen elements according to twenty-one selected factors, each of which is weighted according to its relative importance. The index is determined by the overall weighted ranking of each element. This approach has considerable merit and may be of value to designers of information stockpiles.

Substitute or Alternative Raw Materials

In addition to the substitution of one alloy for another to resolve a raw material shortage problem, we also need to consider alternatives for raw materials sources indigenous to the United States. These include, among others:

1) the national stockpile
2) mixed and/or contaminated scrap
3) specialty steel wastes not currently recycled

The need for information on the stockpile is related primarily to the quality level of some of these stocks. A good example is cobalt. Most of the presently stockpiled cobalt does not meet the chemical specifications required for melting of critical superalloy components. GSA is attempting to resolve this problem by purchasing cobalt to a new chemical specification. But, in the meantime, we are missing certain information including the actual complete chemistries of

the present stockpiled cobalt. It is my understanding that an effort is being initiated to characterize the present cobalt. But the plans beyond that stage are unclear. Information with respect to methods by which the stockpiled cobalt could be upgraded would be of considerable value even if that upgrading is not carried out as part of a planned program. The existence of information with respect to what type of refining would be required in order to utilize the existing cobalt could be of considerable value in a national emergency. It is obvious that if such cobalt were all that was available, specialty steelmakers would find a way to utilize it. The value of prior information would be in shortening the time period required to develop the optimum method of upgrading that cobalt. A corollary would be to develop in advance more information with respect to certain residual elements in critical superalloys. This would permit producers and manufacturers to make decisions with respect to the time and cost of upgrading versus the effect of somewhat lower purities on material performance.

Studies of the availability of critical scrap metals containing chromium in the United States[1,2] indicate a very high percentage of superalloy scrap is apparently being downgraded; that is, used in less critical applications or alloys. This not only in many instances wastes some of the critical

materials contained in these alloys, but significantly increases the need for primary high quality raw materials. A follow on program by International Nickel[3] has resulted in a potential method of reclaiming some of this downgraded material, but at present there is no production facility to accomplish this. In the meantime, information could be generated with respect to a) methods to minimize the contamination or mixing of high quality scrap so as to permit its recycling in the same class alloy, and b) (again) more specific information on the effects of various residuals on alloy performance. The first of these items will be addressed in an AISI symposium to be held in October of 1981. The second item, which is common to utilization of off-prime stockpiled materials, will require a comprehensive study on the effect of individual elements in critical superalloy applications. Some work has been done in this area, but additional information is required to insure that we are not wasting critical raw materials by downgrading unnecessarily.

Some feeling for the extent of this problem can be gained by comparing the scrap usage patterns for superalloys and cast heat and corrosion resistant alloys versus the pattern for use of scrap in stainless steels. The percentage of home scrap generated as a percent of total melt is not too different for high temperature and stainless steels -- 49% versus 40% respectively.

The percentage of prompt industrial scrap as a percent shipped is similar -- 25% for high temperature alloys and 19% for stainless. The percent of home scrap lost or downgraded as a percent of that generated is similar; 13% versus 9%. The major difference lies in the percent of prompt industrial scrap which is lost or downgraded in high temperature metal production; namely, 62% of the total generated versus 7% lost or downgraded for stainless steels. Some of this difference relates to the cost of properly segregating the high temperature scrap versus the price which can be obtained for it in downgraded applications. In addition, there are restrictions with respect to utilization of certain types of scrap which are imposed by the end user. Information with respect to the effect of various residual elements and improved efficiency of scrap segregation could significantly improve the recycling efficiency of critical raw materials in the high temperature alloy field. This information would be extremely valuable in the event of a national emergency or a significant decrease in the availability of selected critical raw materials.

More information on methods to recycle specialty steel waste products can also contribute to increased efficiency of critical raw material recycling. This particular subject will be the major focus of the AISI symposium previously mentioned. Recycling information of this type will not only improve the efficiency of our utilization of critical raw materials in normal

times, but could significantly reduce the requirement for high quality virgin materials in a national emergency when the demand for superalloys would be high and availability a question mark.

Basic R & D as an Information Stockpile

Obviously, basic R & D will be of little value in an emergency situation which requires an immediate solution even if that solution is not perfect. There are potential situations, however, where we have time to develop completely new alloys aimed at reducing the content of a critical raw material. As indicated in prior papers at this workshop, several programs are now underway in an effort to develop lower cobalt, high temperature alloys. Basic research on the effect of cobalt, rapid solidification technology, residual element effects, melting and remelting processes, powder metallurgy, etc. all provide information sources that can be tapped in programs of this type. We must increase basic R & D in the materials field in the United States. I am deeply concerned that decreased effort in basic R & D in the United States in the past ten to twenty years has seriously depleted our stockpile of that kind of information. To date, it has probably not created any major problems, but we cannot continue to withdraw capital without sufficient replenishment. Basic research is a long-term investment. One of the major criticisms of basic research in some quarters is its

inability to provide a quick return on investment. Critics of basic research and development complain that it is undirected, it is not aimed at a specific problem area. This is, in fact, one of the strengths of basic R & D. Our present inability to accurately predict the future with respect to potential shortages of critical raw materials demands a broad base of basic R & D, even if such information will not solve problems overnight. This country needs to be concerned not only with the short-term, but the long-term. Basic R & D is an essential source of information for increased technological advances in the materials field.

In summary, the development of an information stockpile requires:

1) A definition of critical materials and, if possible, an assigning of priorities based on expected or potential future shortages;
2) The development of information on improved segregation of prompt industrial scrap, especially in superalloy field as the means of conservation and an alternative source of critical raw materials in time of need;
3) Development of information on upgrading of off-prime stockpiled materials to permit their rapid utilization if a national emergency arises.

4) Information on the specific effect of residual or tramp elements and combination of those elements to permit tradeoffs between the quality of available or upgraded raw material versus performance of alloys produced from those raw materials;

5) Increased basic R & D to provide information that can be utilized in years to come as unpredictable changes in the political, social, and economic climate of the world create new raw material crises.

---

[1] Availability of Critical Scrap Metals Containing Chromium in the United States. Part I: Superalloys and Cast Heat Resistant Alloys. OFR No. 8(1)-80 (Bureau of Mines), L. R. Curwick, W. A. Petersen and H. V. Makar, November 1979. Contract J0188056.

[2] Availability of Critical Scrap Metals Containing Chromium in the United States. OFR(2)-80 (Bureau of Mines), C. L. Kusik, H. V. Makar and M. R. Mounier, November 1979. Contract J018870.

[3] Process for Recovering Chromium and Other Metals from Superalloy Scrap. OFR 69-80 (Bureau of Mines), J. J. deBarbadillo, J. K. Pargeter, and H. V. Makar, April 15, 1980. Contract J0188056.

SUBSTITUTION PREPAREDNESS - ROLE OF COLLEGES AND UNIVERSITIES

Ellis D. Verink Jr.
University of Florida

SUBSTITUTION PREPAREDNESS . . . ROLE OF COLLEGES AND UNIVERSITIES

Workshop on Conservation and Substitution Technology
for Critical Materials
15-17 June 1981
Vanderbilt University
Nashville, Tennessee

Ellis D. Verink, Jr.
University of Florida

Among the suggested responses to the critical materials problems identified at the "Workshop on Critical Materials Needs of the Aerospace Industry"[1] in February 1981 were:

"a. A physical stockpile of critical materials of the proper quantity, composition and form to accomodate stockpile goals;

b. The development of an "intellectual stockpile" of research and development information as well as the accompanying manufacturing technology to permit rapid substitution for unavailable critical materials should the need exist;

c. A positive industrial effort to seek suitable substitute materials and/or develop designs, etc., which permit use of less critical materials or alloys using smaller quantities of critical materials..."

The academic community can contribute to the accomplishment of each of these responses in collaboration with industry and government.

1. Workshop on Critical Needs of the Aerospace Industry, February 9-10, 1981, NBS, Gaithersburg, Maryland.

Background

The primary "products" of colleges and universities are students. It is expected that Bachelor degree students in engineering and the physical sciences will be well grounded in mathematics, and have a feeling for applied sciences. To deal effectively in today's climate, they also should have a sensitivity regarding critical materials, think in a "systems concept" (e.g., have an appreciation of how materials must work together), and a working knowledge of engineering economy. To contribute most effectively to substitution preparedness, students will require thorough grounding in principles of metallurgy and materials in addition to a well rounded scientific or engineering background. Bachelor level graduates normally are engaged primarily in production and processing of materials and general engineering pursuits.

Graduate students in metallurgical and materials engineering at the Master's and Ph.D. level normally start with the Bachelor level training indicated above and supplement this with advanced coursework and academic research experience in preparation for careers in advanced technology and research. As a consequence, a Ph.D. graduate will have demonstrated special knowledge of research techniques, an ability to define and focus on a research problem, and an "intuition" regarding research opportunities. Such an intuition is especially helpful in considering substitution preparedness.

Faculty and graduate students at universities having graduate programs in metallurgy and/or materials engage in research in one or more of the basic fields of metallurgy including physical metallurgy, process metallurgy, fabrication and joining, extractive metallurgy and mineral processing as well as in the field of non-metallic materials such as ceramics, polymers and composites. Faculties of such universities represent resource pools for consultation and collaboration.

Economic realities force individual companies to concentrate their primary research efforts on proprietary research in support of products and services supplied by that company. Often this results in little or no opportunity to engage in long range activities such as fundamental research or the storing up of substitution technology research. Industries probably will need governmental incentives to engage in substantial research and developmental activities to support responses (b) and (c) above. On the other hand, universities favor research in fundamental areas (i.e., non-proprietary research) which can be the basis of scholarly publications, master's theses, or dissertations. This provides an outstanding opportunity for collaborative research between industries and universities with the universities specializing in non-proprietary aspects and feeding the results to industries for adaptation to proprietary interests. Likewise, research in support of conservation and substitution technology would be ideally suited to universities. While serving these research needs, universities also would be fulfilling their primary educational function by producing graduates sensitized to the needs of conservation and substitution.

Technology Transfer

The incorporation of information on substitution preparedness technology is well adapted to normal academic activities. For example, such information is readily included in classroom lecture material, homework assignments, term papers, and problems. In order to accomplish this task it merely requires emphasis on applications of materials, selection and substitution of materials, etc. Problems requiring optimization in choices of materials based on availability, economy, net energy costs, recyclability, conservation of critical materials, etc.,

provide students with first-hand experience. At the University of Florida, such activities have been in progress for several years and student reception has been excellent. Another effective tool has been the conducting of student contests for papers and term projects on subjects dealing with selection and substitution of materials.

Research Opportunities

There is a wealth of appropriate research topics to challenge graduate students while supplying vital information for substitution preparedness. Examples of such research areas include:

1. RST materials; detailed metallurgical knowledge of mechanisms and processes to optimize properties; characterization, deformation processes, etc.
2. "Forgiving ceramics" - ceramics with improved ductility or enhanced resistance to crack extension. Basic understanding, proof of concept, optimization.
3. New alloys strengthened by intermetallic compounds (e.g., Ti-Al, Fe-Al) - mechanisms of strengthening process, control of properties, characterization.
4. Evolution of structure and properties of powder metallurgy materials as a function of processing variables, composition, etc. (e.g., aluminum).
5. Interfacial characteristics and problems related to use of coatings containing critical materials on substrates of non-critical materials. Mechanisms of adhesion, resistance, protectiveness, repair, etc.
6. Mechanisms of failure of composite materials. Strategies to avoid failure under various conditions.

7. Alloy development focusing on systems based on available minerals (e.g., Ni, Fe, Ti, Al, Mo, W) and on alloys more dilute in certain critical materials, notably Co, Cr, Cb, Ta.

8. etc.

Realities

The funding of universities tends to be based either on "formula funding" or "project funding" or a combination of the two. Under formula funding, funds are provided in accordance with the so called "body count." This concept is particularly applicable to situations involving very large classes such as those encountered in chemistry, physics, mathematics, humanities, language, etc., and may also be appropriate for certain large engineering disciplines such as electrical engineering, mechanical engineering or civil engineering. However, in the case of substitution technology, perhaps the most important disciplines will be metallurgy, ceramics, polymers, etc., fields in which the total number of students is not large. For example, during the last year there were approximately 1,000 graduates in metallurgy produced by some 86 departments. This gives a national average graduating class of just under 12 per year in metallurgical engineering. The fields of ceramics and polymers are even smaller. The industrial demand for metallurgy and materials graduates is several times the annual production. Small disciplines such as metallurgical and materials science are not likely to survive under formula funding. As a consequence, a few universities have taken steps towards project funding for such smaller disciplines. Special efforts must be made both by industries and government (both state and national) to be certain that vital disciplines such as metallurgy, materials science, ceramics and polymers survive in order to assure a

supply of prospective employees.

At present the Federal Government provides approximately 85% of the total research support as compared with 10%-12% coming from industrial sources. In order to maintain the research capability of universities and colleges and to provide graduate training for personnel to handle advanced technology in connection with substitution of materials, it is important that there be dependable research support. Both industry and government have an enlightened self interest in maintaining such support.

Conclusion

1. The academic community has unique capability and intellectual orientation to participate in the accomplishment of substitution preparedness.

2. Dependable long term financial resources will be required to assure the participation (and in a number of cases the continued existence) of departments of metallurgical engineering, materials science, ceramic and polymers.

3. There is another critical "commodity" for which a substitute is not available. This critical commodity is graduates. Happily, this is a "renewable resource" and under proper cultivation and nourishment, the crop can flourish and help solve the problems of substitution technology . . . but help is needed.

SUMMARY AND OVERVIEW OF WORKSHOP

N. E. Promisel, Consultant

&

Allen G. Gray, General Chairman

Summary and Overview

of

Workshop on Conservation and Substitution Technology for Critical Materials

by

N. E. Promisel, Consultant and
Allen G. Gray, General Chairman of Workshop

The United States is heavily dependent on foreign sources for supplies of key materials essential to the nation's defense and to the operation of its vital industries. This country, for example, imports almost 100% of its strategic metals -- cobalt, chromium, columbium, tantalum, and manganese. Over-all, the United States depends on foreign sources for 22 of the 27 metals considered vital to the country's economy.

To meet the challenge of this enormous dependency, all options to provide supplies or alternatives must be pursued. On the supply side, effective steps are needed to strengthen the strategic stockpile and to develop domestic resources. The other option is a viable materials and processing technology for alternatives at reasonable cost. Alternatives include substitution, conservation, enhanced performance alloys, coating and surface modification systems, and reclamation.

This workshop was developed as a contribution to the national effort on the issue of materials dependence with the viewpoint that technology for alternatives is among the most viable options for reducing this country's vulnerability to strategic materials. The message from the workshop was clear: The time to start to develop these technologies and build an information stockpile on substitution and conservation is now.

The workshop considered four materials: chromium; cobalt; tantalum and titanium. This was in accordance with the request of the sponsors (see charge to workshop).

Chromium

The U. S. is a major consumer of chrome ore, and is dependent for chromium on essentially a few foreign sources where supply could be shut off with appalling speed (e.g. S. Africa, USSR, Zimbabwe). Domestic ores are negligible. Sixty-two percent of U. S. consumption is for metallurgical applications, and two thirds of this is for corrosion-resistant steels, much of the rest going into high-strength and high temperature alloys.

Obviously, this is a precarious position. For critical applications, in superalloys, chromium is vital. However, for less critical applications, in the major field of use, namely corrosion-resistant steels, there are possible substitutes; for example, titanium, coated low- or no-chromium alloys, modified or new alloy systems like 9Cr1Mo, or MnAlFe. A computer alloy design system has been developed that could be used to design low- or no-chromium systems for heat treatable steels to meet pre-established criteria.

In brief, chromium is vital for many uses but in many other uses we can conserve or eliminate chromium, retaining it for the vital applications. Accordingly, it appears highly desirable to document and evaluate information on technology for substitution and conservation and have this intelligence available for ready use in an emergency situation. Likewise, it would be desirable to develop and support research to expand the substitution information stockpile giving priority to those areas where there is both urgent need and a reasonable probability of success.

As one of the workshop participants expressed it: "It is difficult to overstate the importance of chromium as an alloy addition and the economic disruption that would accompany an interruption of supply. Dependence on chromium is so broad economically that substitutes must be developed if the nation is to realize political freedom of action."

Cobalt

Cobalt supply has some similarity to chromium and some differences. The similarity lies in that we are again heavily dependent on foreign sources, some of dubious reliability. It differs in that we have a few reliable sources and even prospect of domestic supply, not to mention the ocean sea beds. But the geopolitical situation and the supply/demand market have been such that the price of cobalt in the last few years has risen dramatically. So, unlike chromium, criticality of cobalt is not so much a basic scarcity as it is a matter of economics. Now almost one half of cobalt used in this country goes into superalloys, and another total of about 30% into magnetic materials, and in cutting and drilling tools as a bonding agent for cemented carbides.

For superalloys, substituting nickel and other elements for cobalt is taking place, or conserving it through techniques such as near-net shape processing. In magnets, replacement of cobalt seems to be no problem; in fact, replacement materials (e.g. containing rare earths or iron-chrome combinations) may have advantages. Boronizing will produce hard, wear-resistant surfaces to replace cobalt-bearing alloys. Various carbide coatings on cutting tools extend their life, thus decreasing cobalt requirements. New particle metallurgy technology has enabled the complete elimination of cobalt in certain high speed tool steels.

Tantalum

The tantalum situation is different from that of either chromium or cobalt. The U. S. has no reserves, although it has some low-grade resources that might some day come into use. So the U.S. imports about 97% of its needs. However, a significant amount comes from more comfortable sources: Australia, Canada, Brazil, Thailand. On the other hand, when it comes to replacing tantalum with something else, the picture is bleak. Two-thirds of our tantalum goes into capacitors, to a major degree critical, as for example in control systems for jet engines, and for this type of critical application there is no substitute without paying a penalty in performance or reliability.

About 17% goes into metal working machinery and in tools as carbides and here we can conserve and substitute. Eight to ten percent goes into aerospace structures and superalloys and for these applications there appears at this time to be no outright replacement, but there are opportunities for conservation; for example, extended life turbine blades directionally solidified, or single crystal blades, or near-net-shape processing, or new kinds of alloys produced by rapid solidification techniques.

Due to demand exceeding supply, the price of tantalum has increased dramatically in the last few years. This made it worthwhile to re-open marginal mines and also to begin to use marginal tin slags (the other major source of tantalum). As a rsesult, supply has recently increased to the degree that supply and demand are currently in rough balance. If the price remains at its current level of about \$85/lb, supply is likely to be adequate for the near future, so again economics is controlling a very sensitive supply-demand balance and it behooves us not to be smug about it. For example, urgently needed tantalum for single-crystal turbine blades (12% tantalum) could seriously disrupt this balance.

Titanium

The situation here is different than in the case of the other three metals. There is no shortage of raw material, even in the U. S. Facilities are the problem, like sponge-producing equipment, or melting or forging equipment. The erratic demand picture for titanium, ever since the industry started, has prevented the industry from becoming stabilized or having enough confidence in projected demand to invest the necessary heavy capital for expanded and improved facilities, although steps in this direction are now planned.

The aerospace industry, strongly influenced by the Federal Government action, has been the prime user of titanium, and therefore, the cause of its ups and downs in demands. Increased growth of the non-aerospace industry is a stabilizing tendency. Yet, without titanium, aircraft would be heavily penalized in terms of weight increase; and weight increase today means not only a performance sacrifice but also an operating cost penalty due to the high cost of fuel. It has been said that 1 lb of saving on a commercial airplane may be worth \$300-\$400.

Titanium's cost inhibits its greater usage but cost is expected to drop. So in the sense of usage, titanium is critical, but not in the sense of raw material supply. There are possibilities for substitution and conservation: composites; new and improved aluminum alloys using rapid solidification techniques; powder metallurgy, precision casting, and other near-net-shape processing. Titanium is also a potential substitute for other materials, like corrosion-resistant stainless steels.

Technologies for Displacement

In discussing the four critical materials, reference was made to the potential of new types of materials and new process techniques that are emerging. Composites, particularly at the present time the carbon/epoxy types in aerospace applications, not only can save critical weight and provide superior performance, but can also serve as substitutes for titanium and for other materials containing at least some of the above critical materials. In the same context, the increasing consideration of using composites in the automotive and other non-aerospace industries has impressive materials implications for the future (incidentally, conserving fuel due to decreased vehicle weight).

In the decade ahead, high temperature composites using metal or ceramic fibers in metal or ceramic matrices should prove interesting and increasingly applicable and are examples of where research and development are currently needed to provide basic understanding of behavior, improved material properties,and processing and design concepts adaptable to brittle or near-brittle materials. In connection with the latter, monolithic ceramics, especially silicon carbide and nitride, offer very interesting possibilities particularly in selected elevated temperature applications.

Coatings and Surface Modification Systems

With respect to coatings and surface treatments, there are so many operating techniques available that it appears that practically anything can be coated with anything to serve a predetermined objective. Thus a material lean in critical elements and

functionally suitable in every respect except resistance to a hostile environment can very likely be protected against that environment.

Surface treatments ranging from angstroms to an inch thick on a noncritical metal or alloy can often provide the wear or corrosion resistance of solid critical materials.

Coatings can also be used as thermal barriers to lower metal operating temperatures thus permitting use of leaner alloys in many cases for the same performance requirements.

Surface treatments that conserve expensive and/or critical materials include cladding, hard facing, surface alloying, electron beam irradiation, sputtering, and thermal spraying.

Cladding, like coating, makes it possible for a relatively small amount of a critical material to go a long way. Properly applied materials can often provide all the advantages of a solid critical alloy composition.

Hard facing is a form of weld overlay surfacing. Alloys used generally fall into one of four classifications: cobalt base, nickel base, iron base, and tungsten carbide composites. There is considerable effort to reduce the cobalt content in wear resistant surface alloys.

Perhaps the greatest opportunity for the application of hard facing technology to conserve critical materials is a design for maintenance philosophy. Rather than attempt to design the entire body of a component out of a highly alloyed strategic material, opportunities exist to construct the part using less critical materials and then hard face the surface with a suitable alloy to resist wear.

Surface alloying offers a significant opportunity for conserving critical metals such as chromium. Elements are utilized in the most effective manner by placing them on the surface where they are required for corrosion, oxidation, or wear resistance. Application techniques include high temperature diffusion, selected surface melting, and ion implantation.

Ion implantation involves a plasma of ions driven by an electrical charge. The resultant surface alloy is in the range of 500 to 3000 angstroms (50 to 300 nm) thick.

Laser alloying is generally in the development stage. It offers good control, selected area treating, and limited heating of the substrate. In laser glazing, a thin layer of the substrate is melted with an alloy addition and rapidly self-quenched.

Wear resistant surfaces are also produced by pack or salt bath boronizing. Metal carbides are formed by reaction or infusing metals and carbon in the steel. Use of boronizing for the bearing surfaces of journal bearing-type rock bit head sections has been a successful replacement for cobalt base alloy applications.

Another Challenge: Better Use of What We Have

A strong point made in the workshop was that research should be directed toward the development of material technologies that utilize domestic and near-domestic metal resources to the fullest extent.

For example, manganese is of interest in the long term as a resource in alloy systems utilizing aluminum to substitute for chromium in stainless steels. The potential for abundant supplies of manganese from ocean mining of nodules suggests a long-term research support for use of manganese in alloy design.

Molybdenum has great potential for substitution for critical metals. As was noted, chromium is widely used as a hardenability addition for steels and irons, and molybdenum can play a valuable substitution role in this application. Applications of vanadium for heat treated steels offer possibilities.

In conventional superalloys, the contribution of tantalum to high temperature creep resistance can be performed by a combination of columbium, titanium, and hafnium carbide strengthening, plus molybdenum and tungsten solution strengthening. Tungsten is now considered as a "safe" element to be used as a replacement for critical elements.

Molybdenum as an alloying element in stainless steel offers economically competitive substitutes for titanium in most of its corrosion applications.

Nickel provides many opportunities for alloying use as an alternate to chromium, cobalt and titanium should the availability of these elements be seriously restricted. Considerable progress has already been made in substituting nickel base alloys for those containing large amounts of cobalt.

Stockpiling of Information on Substitution Technology

An important topic was considered in the concluding workshop session: stockpiling of information on substitution technology. The concept is to prepare a data base and bank of technical properties of potential substitutes including processing information for critical materials that could be used to accelerate substitution in an emergency. Several existing systems and information centers were described as having the capability of storing, retrieving and disseminating technical information; and what would be needed to expand a system adequately was explored.

The basic concept itself was carefully examined in terms of its advantages, problems, scope and cost. It was clear that a "substitution preparedness" system was highly desirable, but that the development and selection of such a system should be approached carefully, with proper planning, and preferably on an experimental trial basis at first. As previously noted, the selection of chromium for a pilot study would serve a most useful purpose.

A national materials substitution data base to be of broad use should include information on manufacturing processes and design/materials interactions. The development of such a data base would be a major undertaking, but without such a starting point, national response to material shortages would be at a disadvantage with little available guidance. Stockpiling of critical materials has long been considered and has been implemented to a degree. However, the workshop stated that it is also important to stockpile the information needed on how to use alternate materials and that action should be taken now to establish a Materials Substitution Information Data Bank.

Suggestions For a Role of the Government

In spite of what is being done to prevent or alleviate shortages, there are causes for concern, as has been explained: either a transient shortage disruptive of urgently needed production or a continuing shortage that could be disastrous, both cases of vital concern to national security and industrial health. Awareness, alertness, and preventive activites are necessary -- and this means activity and not rhetoric.

These activities are driven by the issues of availability, cost, or performance. As brought out in the workshop, incentives of cost reduction or product improvement or new markets have stimulated industry, as well as the Government, to do many things along the lines of substitution, conservation, and technology development. However, when it comes to timely availability, it seems advisable that the Government play a leading role.

Some general deductions pertaining to the Government's role are summarized below:

1. There must be a clear definition and appreciation at all levels of the nature and magnitude of the problem, not in generalities, but specific with respect to each potentially critical commodity.
2. There must be a long-term, related, comprehensive policy, an implementing plan, and suitable strategy and resources to go with it.
3. Achievement of stockpile goals, in terms of both quantity and quality, must be accelerated.
4. Where there is no realistic incentive for industry to invest heavy capital in high-risk or long-term research and development which, however, shows promise of ultimately aiding availability, then support, or at least seed money, should be provided. Examples are basic research to understand the functional behavior of critical elements, as illustrated in current work on cobalt; or the exploitation of RST; or computer design of alloys to avoid critical metals.
5. As a preparedness measure, generic technology that cuts across many industries and many types of applications should be supported, even though in some cases they cannot be immediately related to an immediate specific mission or problem.

6. Action should be taken toward developing a plan for generating and storing a substitution data base, taking into account the many caveats expressed at this workshop, so that it could be utilized as an aid in an emergency to minimize delay and redundancy of effort. In this respect, the time, effort and cost to bring a development from the laboratory to practical fruition, with adequate data for designer confidence and manufacturing capability, with demonstration of reliability, should by no means be underestimated.
7. Consideration should be given to establishing some type of national advisory and/or coordinating group, specifically related to critical materials issues, consisting of representatives from Government, industry, and academia, in a cooperative and non-adversarial climate.
8. Renewed efforts should be made to establish an early warning capability for threatened shortages of critical materials or threatened unusual commodity price increases, with a mechanism for broadly disseminating such information to permit all sectors to take appropriate protective or evasive action. With this and other Government informational aids, industry itself, as is most appropriate, should then be in a better position to make commodity projections of a type and in a manner most applicable to its own specific needs.
9. It is clear from this workshop that there are impressive technological developments, in being and on-coming with extensive critical technical information not adequately known to those who could use it to alleviate supply/demand problems. Assistance should be provided in collating, analyzing, and distributing such information and technology when not proprietary or otherwise restricted.

Responsibilities of the Private Sector

With a continued program of cooperation, and with all the technical talent that exists in this country, there is little doubt that much can be done to reduce the threat of supply shortages that could devastate the nation's security or industrial health.

The business sector should assume responsibility to maintain an awareness of critical material requirements in new product and process developments and in long term planning. Technical responses should include research on substitution alternatives and development work in cooperation with customers and suppliers which focuses on systems based on available metals and alloys with only small additions of critical materials.

Also, work should be pushed to enhance the mechanical properties of less critical alloys to improve performance requirements. Application of advanced materials and coating systems to reduce the over-all need for critical metals should be studied.

Finally, it is important that information on critical materials issues and on work needed be discussed openly at all levels within a company and especially at corporate levels where priority assignments are made.

SUMMARY OF FINDINGS

SUMMARY OF FINDINGS

Using the information obtained from the workshop participants in the brainwriting exercise, forty findings were developed. These forty findings are presented in rank order of agreement in Table I in their entirety. The first twenty-eight findings which showed a high level of agreement are grouped according to topic below. Only an extract is used when the finding is lengthy.

Technological Information - Displacement and Substitution of Materials

To reduce the use of critical metals, technological information must be developed, organized, and applied. The findings show a desire for additional information on alternative materials and their processing, and the development of an information stockpile on substitution technology.

The findings showed a desire for improved organization of technological information. Information useful primarily in an emergency could be organized into a stockpile.

RANK	
3	... information needed for substitution of chromium ··· the substitute material for the component will have to be a material which has already been qualified ···
6	Another extremely important part of the data required for emergency substitution would be the corrosion resistance in hostile environments.
12	Emergency substitution would require data on alloys derived from reprocessed material of doubtful origin. Thus, knowledge of the impurity efforts would be needed.
20	Current information systems do not often record the properties of non-standard grades.

There are opportunities for conserving critical metals through the use of coatings. However, additional information must be developed to take full advantage of the opportunities.

RANK	
5	Good opportunities exist for conserving large amounts of critical materials through the use of coatings, claddings, and various forms of surface alloying ··· there is reluctance to take the risk of putting these coatings into active service in cases where failure of the coatings could cause hazard ··· or large economic liability ···

8 There are incentives, both economic and technical, for coating corrosion - or wear-resistant materials to enhance their surface properties. What is needed particularly is more work (research) to give confidence that we can coat mild steel ···

16 Information concerning coatings that might be used to lower chromium use in materials would be desirable.

25 One particularly promising coating is surface alloying ··· one problem is that properties necessary in the core material may be affected unpredictably, or may actually be degraded ···

The lack of information concerning materials which could be used as substitutes for chromium bearing alloys was brought out in the findings.

RANK

17 Good data are severely limited for chromium-free alloys which could be used as substitues under demanding conditions.

23 There may be substitutes for chrome bearing materials with acceptable mechanical properties, but information about melting, casting, machining, joining, and heat treating is needed ···

The removal of chromium from high temperature , corrosion resistant, alloys is not possible based on current technological information.

RANK

22 ··· the high temperature corrosion and oxidation resistance provided by chromium makes substitution for it in these applications difficult ···

The use of composite materials in aircraft structures will indirectly reduce the use of critical metals.

RANK

14 ··· organic matrix composites ··· will result in a weight reduction of about 20 percent in aircraft which will allow for downsizing of engines and a decrease in the use of critical materials ···

Process Development to Conserve and Enhance Properties

The findings demonstrated the advantages associated with cleaner, higher quality, powders which could be used to form near net shapes and reduce the use of strategic raw materials needed to produce a component. Research should be pursued to clarify the potential for rapid solidification technology to conserve critical metals.

RANK

9 Cleaner powders are essential for increased use of near net shape production processes.

15 Gas atomization is one particularly promising RS technology. Other methods may also have commercial potential, for instance, some version of melt spinning.

19 One problem with powder technology has been reproducibility and quality control of the powder.

28 The increased alloying levels and homogeneity of RST powder appear to be unusually attractive in disc development -- particularly when coupled with near net shape superplastic forming technology.

The employment of rapid solidification depends in part upon the development of particular technological information.

RANK

7 ··· analysis needs to be performed to correlate particle size to strength and toughness improvements, and to establish the comparative advantage of RST to the traditional hot worked metals.

Composite materials offer opportunities for the displacement of critical metals, given additional technological information.

RANK

21 ··· metal matrix composites may have the capability to displace some superalloys containing Co and Cr. Metal matrix composites is an area needing continued development.

27 ··· development is needed to raise the temperature ceiling of polymeric materials for moderately elevated temperature application.

Environmental factors may inhibit the development of processes to obtain titanium from domestic sources of ilmenite.

RANK

24 ··· Domestic ilmenite (rather than foreign rutile) could serve as a source of titanium in an emergency ··· attention needs to be paid to ferric chloride pollution.

Corporate Policy and Role of Government

Corporations are not likely to commit money and time to the development of substitutes which might be used in a future emergency, if those currently in use are technologically and economically satisfactory. Government support is needed to develop stand-by information for emergency substitution.

RANK

11 It is difficult to justify large industrial R&D expenditures on substitutes at times of ready availability and low cost of a critical material ···

development of information on emergency substitution for, and displacement of, chromium will require substantial funding from Government···

13 The basic role of Government is to perform critical basic research that may be too costly and/or too risky for private industry alone (long range/high risk).

Market Development

Market development is the principal barrier to the stabilization of titanium production which would avoid alternate shortages and gluts.

RANK

26 Expansion of the range of uses of titanium through cost reduction, aggressive exploration of new markets, and possibly improved properties are the most appropriate routes to ensure a more stable supply of titanium ···

Economic Influences

Domestic resources, though they may be uneconomic, offer excellent technological opportunities for reducing the use of critical metals.

RANK

1 There are a number of technical opportunities that might be developed and expanded in order to utilize domestically available elements such as nickel, tungsten, vanadium, and molybdenum to substitute, at least partially, for chromium, cobalt, tantalum, and titanium.

Recent price increases for cobalt and tantalum have promoted a strong substitution initiative and retarded expansion in their uses. This is demonstrated by the four findings summarized below

RANK

2 The sharp rise in the price of cobalt has stimulated its displacement in some high temperature and wear-resistant applicaticns.

10 There is a wide spectrum of magnetic alloys where substitution to reduce, or eliminate, the use of cobalt is both technically and economically possible.

4 The high price of tantalum provides a strong driving force for its displacement in certain applications.

18 Considering the small amount of tantalum which is recycled now, and its price, opportunities to recycle more should be identified.

TABLE I

RANK ORDER OF FINDINGS ACCORDING TO LEVEL OF AGREEMENT

ITEM NUMBER	RANK	FINDINGS WITH LEVELS OF AGREEMENT BETWEEN STRONGLY AGREE AND AGREE
51.	1	There are a number of technical opportunities that might be developed and expanded in order to utilize domestically available elements such as nickel, tungsten, vanadium, and molybdenum to substitute, at least partially, for chromium, cobalt, tantalum, and titanium.
8.	2	The sharp rise in the price of cobalt has stimulated its displacement in some high temperature and wear-resistant applications.
58.	3	The information needed for substitution of chromium, as an example, would depend on the warning time prior to the cut-off. If cut-off is immediate, the substitute material for the component will have to be a material which has already been qualified for the application. If information is available in advance, the effect of downgrading can be minimized.
15.	4	The high price of tantalum provides a strong driving force for its displacement in certain applications.
46.	5	Good opportunities exist for conserving large amounts of critical materials through the use of coatings, claddings, and various forms of surface alloying. Many such applications are in use today and others are economically promising. There is reluctance to take the risk of putting these coatings into active service in cases where failure of the coating could cause hazard (e.g., possible jet engine failure) or large economic liability (e.g., possible failure of valve seats in automobile engines). Uncertainty about long-term reliability and lack of dependable inspection procedures for quality control to ensure long-term reliability are impeding the introduction of coatings in some applications.
62.	6	Another extremely important part of the data required for emergency substitution would be the corrosion resistance in hostile environments.
39.	7	Highly dispersed precipitates and increased solubilities of alloying elements are definite advantages of RST. However, further analysis needs to be performed to correlate particle size to strength and toughness improvements, and to establish the comparative advantage of RST to the traditional hot worked metals.
49.	8	There are incentives, both economic and technical, for coating corrosion- or wear-resistant materials to enhance their surface properties. What is needed particularly is more work (research) to give confidence that we can coat mild steel or other nonresistant materials and use these coated materials to displace the highly alloyed materials which require critical materials. This should ultimately be economically advantageous in many applications.
42.	9	Cleaner powders are essential for increased use of near net shape production processes.
9.	10	There is a wide spectrum of magnetic alloys where substitution to reduce, or eliminate, the use of cobalt is both technically and economically possible.
3.	11	It is difficult to justify large industrial R&D expenditures on substitutes at times of ready availability and low cost of a critical material. It is also difficult to predict if and when a material will become unavailable. In such instances development of information on emergency substitution for, and displacement of, chromium will require substantial funding from the Government. Corporations by themselves will not fund such work, nor give it the necessary priority to have the data available for use by anyone at some time in the future.
59.	12	Emergency substitution would require data on alloys derived from reprocessed material of doubtful origin. Thus, knowledge of the impurity effects would be needed.
72.	13	The basic role of Government is to perform critical basic research that may be too costly and/or too risky for private industry alone (long range/high risk).
26.	14	Although organic matrix composites will not play a major role as replacements for high temperature critical materials in aerospace in the 1980's, they are a new class of high performance materials which will compete with the more conventional materials (e.g., aluminum, steel, titanium) in aerospace. Their use will result in a weight reduction of about 20 percent in aircraft which will allow for downsizing of engines and a decrease in the use of critical materials (e.g., cobalt, tantalum) in aircraft engines in the 1980's.

37. 15 Gas atomization is one particularly promising RS technology. Other methods may also have commercial potential, for instance, some version of melt spinning.

63. 16 Information concerning coatings that might be used to lower chromium use in materials would be desirable.

60. 17 Good data are severely limited for chromium-free alloys which could be used as substitutes under demanding conditions.

16. 18 Considering the small amount of tantalum which is recycled now, and its price, opportunities to recycle more should be identified.

40. 19 One problem with powder technology has been reproducibility and quality control of the powder.

61. 20 Current information systems do not often record the properties of non-standard grades.

28. 21 Major technological obstacles in substitution for critical metals in high temperature applications exist. Metal matrix composites have the potential for achieving good high temperature performance. Therefore, metal matrix composites may have the capability to displace some superalloys containing Co and Cr. Metal matrix composites is an area needing continued development.

2. 22 Given current technological knowledge, the high temperature corrosion and oxidation resistance provided by chromium makes substitution for it in these applications difficult, if not impossible.

1. 23 There may be substitutes for chrome bearing materials with acceptable mechanical properties, but information about melting, casting, machining, joining, and heat treating is needed, in addition to mechanical properties.

18. 24 The concern about disruptions or potential disruptions of the availability of titanium components in the United States is different from the concern with the other metals considered at this workshop. Domestic ilmenite (rather than foreign rutile) could serve as a source of titanium in an emergency, if pilot production is undertaken. However, to exploit ilmenite domestically, attention needs to be paid to ferric chloride pollution.

47. 25 One particularly promising coating is surface alloying. It appears to offer a great variety of coating capabilities without fear of spalling or edge effects. One problem is that properties necessary in the core material may be affected unpredictably, or may actually be degraded by the application method (higher temperatures).

20. 26 Expansion of the range of uses of titanium through cost reduction, agressive exploration of new markets, and possibly improved properties are the most appropriate routes to ensure a more stable supply of titanium. There are technology options worth pursuing toward these objectives.

27. 27 Major technological obstacles to using composites as substitutes include elevated temperature performance; both for moderately elevated temperatures (a few hundred degrees C) and high temperatures (vicinity of 1000°C). Further development is needed to raise the temperature ceiling of polymeric materials for moderately elevated temperature application.

36. 28 The increased alloying levels and homogeneity of RST powder appear to be unusually attractive in disc alloy development--particularly when coupled with near net shape superplastic forming technology.

FINDINGS WITH LEVELS OF AGREEMENT BETWEEN AGREE AND DISAGREE

30. 29 Quality control procedures of composite materials fabrication must be incorporated in the fabrication processes. Current NDE procedures are generally inapplicable to the inspection of completed complex composite structures and components.

29. 30 While composite materials manufacturing processes are not considered prohibitively labor intensive in the aerospace industry, they are currently sufficiently labor intensive to pose economic problems for application in the automotive and other non aerospace industries.

14. 31 In the electronics industry, tantalum ranks third in degree of concern, behind cobalt and platinum metals.

31. 32 There is a very large body of knowledge about the resistance of metal alloys to specific and troublesome environments. There are good possibilities for using composites instead of stainless and other corrosion resistant special alloys in such troublesome environments. For example, polymer based composites with graphite or other reinforcements can replace critical metals used in extremely corrosive environments, such as in chemical production and in environmental and maritime service.

38. 33 Use of abundant materials such as Al anf Fe in RST could reduce our vulnerability to foreign suppliers of Co and Cr, but achieving higher performance is probably an even greater reason for developing RST materials.

41. 34 Improved testing procedures, especially NDE methods, will expand the use of near net shape production processes.

65. 35 The ceramic technology offers long range potential for increased performance (e.g. in adiabatic diesels) and decreased dependence on critical metals.

64. 36 Chromium cannot be removed from nickel base superalloys currently used in hot turbine applications on the basis of present information. It may be possible to use claddings to substitute for some of the chromium if adequate information were available.

21. 37 New alloys are needed which are tailored for specific uses. (Titanium)

48. 38 Chromized-coated sheet as a replacement for stainless steel failed commercially for economic reasons only. Chromized sheet would serve as a substitute for stainless steel in many applications and would conserve at least 50% of the chromium now required for stainless steel.

19. 39 There is no current agreement as to which step-sponge production, melting, or mill shape fabrication is the choke point causing shortages, or long lead times, for titanium production.

13. 40 Of the four metals considered in this workshop, tantalum is likely to be the most critical from the viewpoint of substitution. Its criticality may increase with the advent of single crystal blades in jet engines.

SUMMARY OF RECOMMENDATIONS

SUMMARY OF RECOMMENDATIONS

Thirty-seven recommendations were developed using the information obtained from the participants. These thirty-seven recommendations are presented in Table II in rank order of combined importance and effectiveness in their entirety. Additional information obtained from the evaluation is also presented in Table II. The first twenty-seven recommendations which showed a high level of combined importance and effectiveness are grouped according to topic below. Only an extract is used when the recommendation is lengthy.

Stockpiling and Disseminating Technological Information for Displacement, Substitution, and Conservation of Critical Materials

Of the twenty-seven recommendations, ten were related to the need for development, compilation, and dissemination of technological information on displacement, substitution, and conservation of critical metals.

The organization of information for use during an emergency was considered to be an important and effective action that should be taken.

RANK

1 The information stockpile should include as many alternate approaches as possible including substitution, processing, recycling, and alternate sources. ...

2 Emergency substitution for cobalt in military jet engines involves lengthy testing and qualfication requirements. Back-up alloys should be prequalified for use in emergencies, ...

3 A human stockpile of information should be organized which could be employed immediately during an emergency.

5 Existing organizations that collect, stockpile, and disseminate information could stockpile information organized about each of the critical metals.

6 Priorities which would be invoked for allocating critical metals in an emergency should be made known to all concerned industries, ...

RANK

11 Comprehensive examination of the information developed on uses and substitutions of critical metals, such as the NMAB report on chromium, should be conducted periodically. ...

12 ... Government funding of special alloy development and the building of a data base containing the resulting information for use during an emergency. Primary attention should be given to the most critical oxidation and corrosion resistant applications. ...

20 To extend product life Government should promote long term testing, ...and a program to understand failure in terms of mechanism, ...for improving long-term reliability of coated materials.

Dissemination of technological information must be encouraged if reductions in the use of critical metals are to be achieved.

RANK

16 ...professional engineering organizations should encourage universities to emphasize all materials, not only metals, more heavily in Mechanical Engineering curricula....

25 Technical meetings and workshops are needed periodically to focus attention on opportunities for utilization of domestically available materials in place of critical imported materials.

Developing Technological Information for Displacement, Substitution, and Conservation of Critical Metals

Two recommendations, involving studies to develop information which would lead to a reduction in the use of chromium, follow.

RANK

10 In some cases, codes require a high chromium alloy when a lower chromium alloy or even a nonmetal would function equally well. Alloy specifications codes should be reevaluated....

24 ...the U.S. Government may need to generate special incentives...alloy systems could be developed based on manganese and aluminum, and iron and aluminum, which could displace chromium based alloys.

Several types of basic research were recommended by the participants as given below.

RANK

15 Studies in phase equilibrium relationships, structure-property relationships, and solidification mechanism should be stimulated through federal research support.

19 Basic research on the role which critical metals play in alloys would provide information that would be used in the normal materials displacement process... guide effective substitution in an emergency.

22 Although cobalt is known to be an important constituent of high temperature superalloys, its exact role as an alloying agent is uncertain. Additional R&D is needed....

23 The exact role of tantalum as an alloying agent is presently not well understood. Further R&D should be directed to clarifying the role of tantlum....

Due to relative newness of the rapid solidification technology, much basic technological information is needed.

RANK

27 Support mechanisms should be considered for design trade-off, actual part evaluation, and test studies to provide designer and producer confidence in the new technologies....

Process Development

Significant improvements in production processes for titanium are considered necessary, as brought out in the following two recommendations.

RANK

9 ...development of energy efficient alternative reduction processes ...that minimize the number of process steps and thereby provide more economical titanium should be pursued.

23 ...titanium industry should be given a liberal tax credit, or write offs of equipment and facilities, in order to encourage investment in the electrowinning process and other approaches....

Improvements in the evaluation of composite parts is also needed. It is the view of the participants that this development could be implemented through private sector action.

RANK

4 Development of improved NDE procedures for composites should be pursued for use in control of processing, inspection after production and assembly, and inspection after service.

Market Development

The development of more efficient production processes for titanium is heavily dependent upon demand for the metal.

RANK

8 The titanium product shortage is not due to the lack of installed capacity but to lack of long range commitments.... Multi-year procurement commitments are needed....

Economic Influences

The use of domestic materials which are not economic will occur only if government is willing to offer economic incentives. The four recommendations below demonstrate this view.

RANK

7 The Government should...encourage the development of processes for the reclamation of critical metals....

13 Full depreciation in three years or less should be permitted for those fixed capital expenditures which would lead to reclamation of critical metals.

17 Full depreciation in three years or less should be permitted for those fixed capital expenditures which would increase the availability of domestic metals or near domestic metals....

21 The Government should see that adequate substitutes are developed emphasizing domestic materials....

In a more general sense, this view is borne out by the following recommendations. These two recommendations are consistent with the findings.

RANK

14 ...After certain processes with limited aerospace and military application have been shown to be viable, the Government may have to act as "champion" for continuing development and pilot utilization.

RANK

18 The development of conservation options cannot be justified by industry solely as a hedge against possible periodic shortages...protection against future potential shortages is a Government responsibility.

TABLE II

RANK ORDER OF RECOMMENDATIONS

ITEM NUMBER	RECOMMENDATIONS WITH COMBINED LEVELS OF IMPORTANCE AND EFFECTIVENESS IN EXCESS OF THE MODERATE LEVEL	RANK BASED ON: IMPORTANCE & EFFECTIVENESS	IMPORTANCE	EFFECTIVENESS	DISAGREEMENT	MEANS OF IMPLEMENTATION IN ORDER OF FREQUENCY OF SELECTION BY RESPONDENTS (SEE TABLE III FOR DEFINITION OF NUMBERS)				
68.	The information stockpile should include as many alternate approaches as possible including substitution, processing, recycling, and alternate sources. It should be tailored to the specific applications and the properties required.	1	2	1	1	4	2	3	5	1
10.	Emergency substitution for cobalt in military jet engines involves lengthy testing and qualification requirements. Back-up alloys should be prequalified for use in emergencies, if they can provide "almost as good" performance.	2	1	5	6	4	3	2	5	1
66.	A human stockpile of information should be organized which could be employed immediately during an emergency.	3	4	4	8	4	2	5	3	1
35.	Development of improved NDE procedures for composites should be pursued for use in control of processing, inspection after production and assembly, and inspection after service.	4	8	3	2	3	2	4	1	5
70.	Existing organizations that collect, stockpile, and disseminate information could stockpile information organized about each of the critical metals.	5	13	2	9	4	2	3	5	1
74.	Priorities which would be invoked for allocating critical metals in an emergency should be made known to all concerned industries, to encourage rational planning for emergency substitution.	6	3	12	3	4	2	5	3	1
57.	The Government should, through some incentive, encourage the development of processes for the reclamation of critical metals wherever possible. Such technologies have been under consideration for years, but most are not economically attractive to industry without incentives.	7	6	6	32	4	2	5	1	3
24.	The titanium product shortage is not due to lack of installed capacity but to lack of long range commitments on the part of users which would allow better scheduling. Multi-year procurement commitments are needed and better and more stable forecasts of needs.	8	7	9	33	4	2	3	5	1
23.	The current costs of titanium and titanium alloys are relatively high. The development of energy efficient alternative reduction processes (such as direct reduction from chemical precursor to alloy powder) that minimize the number of process steps and thereby provide more economical titanium should be pursued.	9	5	15	12	4	3	2	1	5

7.	In some cases, codes require a high chromium alloy when a lower chromium alloy or even a nonmetal would function equally well. Alloy specifications codes should be reevaluated by the originating organization in light of current technology, to determine if high chromium steels are indeed needed for the current applications. Appropriate technological information should be provided to back up recommended modifications.	10	9	14	5	4	2	3	1	5
69.	Comprehensive examination of the information developed on uses and substitutions of critical metals, such as the NMAB report on chromium, should be conducted periodically. High priority should be given to this particular metal. Useful information would include basic property data, fabrication techniques and requirements, and test results obtained in service environments.	11	17	7	4	4	2	3	5	1
75.	DOC recommendations should include Government funding of special alloy development and the building of a data base containing the resulting information for use during an emergency. Primary attention should be given to the most critical oxidation and corrosion resistant applications. Likewise, data should also be organized for applications where substitution and conservation are not economical under normal conditions, such as with heat treated steels.	12	10	18	29	4	5	2	3	1
56.	Full depreciation in three years or less should be permitted for those fixed capital expenditures which would lead to reclamation of critical metals.	13	20	7	34	4	2	5	3	1
77.	The Government is providing support for critical metals conservation in aerospace materials, i.e., cobalt, through established funding agencies. Large savings of critical metals may be possible in commercial application, but industry may be unable to support such advanced programs. After certain processes with limited aerospace and military application have been shown to be viable, the Government may have to act as "champion" for continuing development and pilot utilization. Methods of providing support would have to be established.	14	15	10	27	4	5	2	3	1
45.	Studies in phase equilibrium relationships, and solidification mechanisms should be stimulated through federal research support.	15	19	11	23	4	2	5	3	1
34.	A big factor involved in achieving greater use of composites in aircraft is the education of designers to consider materials in the early stages of design. To this end, professional engineering organizations should encourage universities to emphasize all materials, not only metals, more heavily in Mechanical Engineering curricula since this is where most design engineers are educated.	16	24	16	19	3	2	4	1	5

55.	Full depreciation in three years or less should be permitted for those fixed capital expenditures which would increase the availability of domestic metals or near domestic metals that are substitutes for critical metals.	17	25	13	35	4	2	5	1	3
76.	The development of conservation options cannot be justified by industry solely as a hedge against possible periodic shortages because the cost of industrial R&D, and its implementation, must be justified by the return on investment regardless of shortage considerations. Investment in such options purely as a protection against future potential shortages is a Government responsibility.	18	21	19	13	4	5	2	3	1
67.	Basic research on the role which critical metals play in alloys would provide information that would be used in the normal materials displacement process where compound performance is a key part. This information would also guide effective substitution in an emergency.	19	26	17	16	4	2	5	3	1
50.	To extend product life Government should promote long term testing, (e.g., of uses in selected Government applications), and a program to understand failure in terms of mechanisms, when it occurs, so that useful guidance can be provided for improving long-term reliability of coated materials.	20	23	20	15	4	2	3	5	1
53.	The Government should see that adequate substitutes are developed emphasizing domestic materials and available for use when needed. Naturally the cost would be a factor for commercial use, but strategic use is not as dependent on cost.	21	14	23	31	4	5	2	3	1
11.	Although cobalt is known to be an important constituent of high temperature superalloys, its exact role as an alloying agent is uncertain. Additional R&D is needed for the study of complex superalloy systems and tool steels in order that the development of substitutes can proceed beyond a purely empirical point.	22	16	22	22	4	3	2	1	5
17.	The exact role of tantalum as an alloying agent is presently not well understood. Further R&D should be directed to clarifying the role of tantalum (structure versus properties) in superalloys.	23	11	27	25	4	3	2	5	1
4.	To ensure the development of process technology for applications of special national interest, the U.S. Government may need to generate special incentives, including the funding of research and dissemination of the results. New alloy systems could be developed based on manganese and aluminum, and iron and aluminum, which could displace chromium based alloys.	24	12	29	14	4	5	3	2	1

52.	Technical meetings and workshops are needed periodically to focus attention on opportunities for utilization of domestically available materials in place of critical imported materials.	25	29	21	7	3	4	2	1	5
22.	New large capacity electrowinning plants employing modern technology to reduce production costs are needed. The titanium industry should be given a liberal tax credit, or write offs of equipment and facilities, in order to encourage investment in the electrowinning process and other approaches in view of potentially adverse market conditions.	26	18	26	30	4	2	3	5	1
44.	Support mechanisms should be considered for design trade-off, actual part evaluation, and test studies to provide designer and producer confidence in the new technologies and generate the data needed for new designs.	27	28	25	24	4	3	5	1	2

RECOMMENDATIONS WITH COMBINED LEVELS OF IMPORTANCE AND EFFECTIVENESS BELOW THE MODERATE LEVEL

33.	The more rapid and widespread use of new and improved fibers and polymeric matrix materials would be accelerated by the orderly compilation and analysis of their physical and mechanical properties over a broad range of temperatures and environments.	28	31	24	10	3	4	2	5	1
32.	The extension of usefulness of metal matrix composites in elevated temperature service conditions could be a valuable contribution in relieving our dependence on chromium and other critical materials. Research and development in this field should be pursued.	29	27	32	11	4	3	2	5	1
73.	Economic incentives for the displacement of some critical metals are weak. Anti trust limitations on cooperative research should be examined to determine whether they can be waived to encourage the development of substitutes for critical metals such as chromium.	30	30	28	28	4	5	2	3	1
6.	The cost and effort required to qualify a material which would displace a critical material (chromium) is a barrier to its displacement. These procedures should be evaluated with the objective of reducing the cost of qualification where possible to encourage displacement.	31	22	33	18	4	2	3	5	1

43.	A National Materials and Minerals Policy should provide tax incentives for investing in commercially-scaled RS technologies.	32	32	34	37	4	2	3	5	1
12.	Attention should be given to the development of non cobalt bonding materials that would function in current machines with little or no change in operational procedure.	33	34	31	20	3	4	1	2	5
71.	Mechanisms should be developed to induce the disclosure of proprietary information on properties of substitutes for critical metals during an emergency.	34	33	35	21	4	5	2	3	1
25.	Better utilization of titanium can be realized through the use of improved scrap reclamation.	35	35	30	17	3	4	1	2	5
54.	Government procurement should be employed to increase the use of domestic metals or near domestic metals while decreasing the use of critical metals in aerospace equipment.	36	36	36	36	4	2	5	3	1
5.	For a "technology stockpile" to be effective in an emergency, a stockpile of capital equipment to implement the technologies may also be required. This is costly. Government financing, or joint Government-private sector involvement, would be required to create a real "technology stockpile."	37	37	37	26	4	5	2	3	1

PROCESS EMPLOYED TO DEVELOP
THE FINDINGS AND RECOMMENDATIONS

PROCESS EMPLOYED TO DEVELOP THE FINDINGS AND RECOMMENDATIONS

Obtaining Information from the Workshop Participants

During the workshop information was obtained from the participants employing a process referred to as brainwriting. In the application of the process a question, written at the top of a sheet of paper, was given to each participant at the end of each session (e.g. Session V-Composites). The participant responded to the question in writing for ten minutes. At the end of the ten minute period, participants exchanged their results. Each participant then expanded upon the statements which he received. After ten more minutes, the paper was returned to the originator and he verified the statements which had been added. Then the papers were collected by the person administering the brainwriting exercise.

Through this procedure, written responses to carefully developed questions were obtained for each session during the workshop. To illustrate the way in which the participants responded, the questions and sample responses are given in Table III. The questions and responses are grouped according to session. The responses show the breadth, resolution, and quality of the information which we obtained from the participants.

Candidate Findings and Recommendations

Following the workshop, the results of the brainwriting exercises were analyzed. Through the analysis a set of findings and candidate recommendations were developed for each session of the workshop. The candidate recommendations and findings are presented in Table IV.

Evaluation of the Candidate Findings and Recommendations

The findings and candidate recommendations were sent to all 180 people who attended the workshop for evaluation on July 3, 1981.

Participants were asked to verify or refute the findings. They were asked to evaluate the candidate recommendations for importance, effectiveness, and means of implementation. They were asked to respond only to the findings and recommendations with which they were familiar. The evaluation sheet which was sent to the participants is shown in Table V.

Replies were received from 93 by July 17, the rating sheet having been returned by 90 participants. The number of responses varied from about 50 to 75 for a particular finding, or recommendation. The results of the verification of the findings by the respondents are tabulated in Table VI. The results of the evaluation of the candidate recommendations by the respondents are tabulated in Table VII.

Rank Ordering of the Findings

The tabulated findings in Table VI were weighted for agreement using the scale given below

Strongly Agree	≃ +10
Agree	≃ + 5
Disagree	≃ -10

This procedure yielded the rank order of the findings which is given in Table I. Twenty-eight of the findings in Table I display levels of agreement between strongly agree and agree. The remaining twelve display levels of agreement between agree and disagree.

Rank Ordering of the Recommendations

The results of the evaluation of the recommendations, tabulated in Table VII, were weighted using the scales given below

1.	Of Major Importance	≃ 10.0
2.	Of Moderate Importance	≃ 7.5
3.	Of Limited Importance	≃ 5.0
4.	Of Minor Importance	≃ 2.5
5.	Of No Importance	≃ 0.0
1.	Very Effective	≃ 10.0
2.	Moderately Effective	≃ 7.5
3.	Possibly Effective	≃ 5.0
4.	Probably not Effective	≃ 2.5
5.	Would not be Effective	≃ 0.0

Of the 37 recommendations, 31 were considered to be at least moderately important by the respondents. The remaining 6 were viewed as being at least of limited importance. Of the 37 recommendations, 21 were considered to be at least moderately effective. The other 16 were viewed as being at least possibly effective. The recommendations are presented in order of combined importance and effectiveness in Table II.

Other results drawn from the data given in Table VII are presented in Table II. The five possible means of implementation given below were used in evaluating the recommendations.

1. Will certainly be implemented through private action alone.
2. Would be implemented through private sector actions with appropriate changes in public policy.
3. Could be implemented through private sector action alone.
4. Is unlikely to be implemented through private sector action without appropriate changes in public policy.
5. Would not be implemented in the forseeable future through private sector action even with appropriate changes in public policy.

The fourth means of implementation given above, involving joint action by the private and public sectors, was selected most frequently for 31 recommendations. The third means of implementation was selected most often by respondents for the other 6 recommendations, as shown in Table II.

Respondents were given an opportunity to disagree with a recommendation, if they felt that the recommendation was defective and preferred not to evaluate it. Twenty-nine recommendations showed disagreement rates below 10%. Three recommendations showed disagreement rates in excess of 20%, with five between 10 and 20%. The rank order of disagreement is given in Table II.

TABLE III

SESSION I — CHROMIUM

QUESTIONS

1. In what cases is substitution for chromium currently most difficult technologically?

2. What are the most promising technological opportunities for
   - economically favorable displacement of chromium (where technological and market opportunities appear jointly favorable)?
   - preparedness, or emergency, substitution for chromium?

3. What obstacles impede the otherwise economically favorable displacement of chromium through technological development, and what future steps favoring these developments should be included in the recommendations which the Department of Commerce makes to the Congress?

4. What obstacles impede preparation for emergency substitution through technological development, and what future steps to improve emergency substitution should be included in the recommendations which the Department of Commerce makes to Congress?

SAMPLE RESPONSES FROM 120 PARTICIPANTS

1. Substitution for chromium is technologically most difficult in the high temperature alloys such as used in gas turbine engines, etc. Replacing chromium for these applications is extremely complex, since the alloy systems tend to be complex - often containing as many as ten or more different specified elemental additions - raising numerous possibilities for detrimental effects of substitution, other than oxidation resistance. Coupled with this is the very demanding "qualification procedures" any new alloys in these applications must undergo, to further discourage substitution efforts.

* I agree with the above and in addition, areas requiring a high degree of corrosion resistance appears to be a difficult area. Present technology on alloys with Cr reduced or eliminated indicate that, in many cases, strength and oxidation resistance can be matched to current stainless grades, but that corrosion resistance cannot, even with many alloying elements of much greater expense. The corrosion resistance of such alloys in the broad range of oxidizing, reducing mineral, & reducing organic acids, and chloride type environments appears to be the area requiring the most work.

1. The most obvious obstacle to Cr substitution is related to spontaneous formation of the protective oxide film at ambient and relatively low temperatures. To my knowledge, no one has been able to replace Cr in this respect. Accordingly, where the beneficial role of Cr in providing passivity is a requirement, Cr cannot be replaced. While there are combinations of alloying elements that confer oxidation resistance at elevated temperatures such as Al, Si, etc. as we have seen, none of them provide the opportunity for the total package of properties that Cr provides. They all fall short in one or more areas such as strength, sulfur resistance, etc. Accordingly, it will be necessary to tailor alloys to much more narrow markets and applications; a factor that tends to complicate development and increase cost consideration.

* This is true but only pertains to essential uses of oxid. & corrosion resistant materials - what about not so critical applications. In that case investment in new technology becomes the roadblock.

1. In hot, highly stressed, and critical components in jet engines. In most alloys now being used the Cr is at the lower acceptable range that will produce the required properties. Cr has been controlled very carefully in the past due to its tendency to form the embrittling sigma phase during exposure to service temp. Generally speaking, the lower the Cr the less tendency to form sigma (assuming all other elements remain constant). Thus, Cr is already on the low side. To date, no other elements can satisfactorily replace Cr in these applications (alloys).

* The addition of 0.1 - 1.0% La has been found to improve oxidation resistance in superalloy. Could that be a modification worth trying (may be patented).

2. The most favorable opportunities are in substitutes for stainless steels. Economically, at low temperatures, because plastics, aluminum, coatings, and claddings will substitute for SS. Preparedness - there is a need for substitutes for 750-800°C applications, and substitutes can be developed for this temperature range. It is more difficult at higher temperatures.

3. Industry has little incentive to develop substitutes for Cr because it is now available and the price has not fluctuated as the price for Cobalt. Therefore, the Government should take the lead in long-range research on chromium substitutes. There are many small deposites of Cr ore, but by the year 2000, the world will depend upon Southern Africa for chromium. Thus, the U.S. must have alternatives.

3. The main obstacle is substitution for chromium would be inertia or the fact that chromium has been economically available to stainless steel makers basically, and to the users of stainless steel. I do not forsee extensive tampering with our free market system in peace time. We could go as far as classifying chromium consumption into three categories. 1) essential 2) marginal and 3) non essential.
That way chromium consumers would have some warning as to whether their availability and access to raw materials would suffer in an emergency. These classifications would have to be widely published.

3. There is substantial lack of economic incentive to do this. It was emphasized over & over that Cr <u>is</u> available and <u>is</u> cheap. The DOC should recommend some economic (monetary or tax) incentive for those who will search for substitution developments even though they can still buy Cr readily in the market.

4. The biggest obstacle is lack of incentive to invest the funds to prepare for substitute materials. The present availability and relatively low price of chromium far outweigh "hypothetical" concerns about future supply problems. Widespread government subsidies to establish the technology needed for chromium substitution would be too expensive if the aim was to cover all possible uses. An alternate approach is for the government to prioritize chromium allocations and make industry aware who would get chromium & who would not in a future emergency. The have-nots would be put on notice to prepare for the future.

4. It appears difficult to justify the allocation of money and manpower required to prepare for emergency substitution in a number of major alloy categories on the basis of a "what if this material is no longer available" supposition. To be truly ready for the worst case situations for, e.g., Cr would require an enormous R&D effort to qualify the alternatives. Possibly, political approaches to reducing or eliminating the threat of supply interruptions would be a more effective approach. Clearly the resources which would have been put into planning for critical material shortages can be utilized in other areas of R&D on materials where they would have greater benefits and not act primarily as insurance.

4. Today, unless there is a cost advantage to be shown, testing of "new" materials in the turbine industry is almost impossible. In current production engines, it takes approximately $500,000 - $1 million dollars to test a new material. In the design of a new engine, cost becomes the over-riding factor in material selection if both materials (new/current) are similar in properties. In fact, with the experience gained in previous engines, it would be very difficult to select a new material without extensive testing (over and above that which is performed on the old material). It goes without saying that in times of shortages, the price of the "old" material increases substantially and the "new" material becomes attractive, but, by then it is too late.

4. In addition to the allocation system, which was used for cobalt after the Zaire situation disrupted supply, incentive for investment in long term R&D must become part of the national materials policy. These incentives could take the form of greater-than otherwise available tax credits for equipment modifications, capital expenditures for new plants, etc.

4. A major obstacle is the idea that U.S. weapon systems must be at forefront of technology when in practice it has no real meaning. The Russians use proven equipment & more simple equipment. Dept. of Commerce should recommend that Defense should analyze weapon systems for use of materials (critical) that cause problems if unavailable. We should try to design critical stuff out.

* Indicates a response to the previous statement

SESSION II COBALT

QUESTIONS

1. In what case is substitution for cobalt currently most difficult technologically?

2. What are the most promising technological opportunities for
   - economically favorable displacement of cobalt (where technological and market opportunities appear jointly favorable)?
   - preparedness, or emergency, substitution for cobalt?

3. What obstacles impede the otherwise economically favorable displacement of cobalt through technological development, and what future steps favoring these developments should be included in the recommendations which the Department of Commerce makes to the Congress?

4. What obstacles impede preparation for emergency substitution through technological development, and what future steps to improve emergency substitution should be included in the recommendation which the Department of Commerce makes to Congress?

SAMPLE RESPONSES FROM 43 PARTICIPANTS

1. From the data given by the speakers it appears that the percentage of cobalt used in superalloys has increased over the last several years. This means to me that due to the high cost of cobalt, manufacturers in most industries are finding substitutes. The increased percentage of superalloy consumption of cobalt indicates, however, that no substitutes exist in this industry. Since developing substitutes for superalloy uses of Co is the most difficult technologically, research like the COSAM program is justified.

1. Believe that the soft magnetic alloys represent a very difficult case. For instance Hiperca 50 or Permcudur type alloys (50 % Co) are critical for maintaining minimal weight/volume packages in aircraft power generation systems. However these systems are present on <u>all</u> military and commercial aircraft. The desired properties for this application involve mechanical and magnetic properties (especially high saturation magnetization). The criticallity of these alloys to aircraft power generation systems should make them a high priority case for technical substitution development efforts. I believe this particular case should be included in the upcoming DOC and DOD reports to congress.

2. Continued work on replacement of Co in magnetic alloys plus work to replace or substitute for Co in superalloys. I do not agree that the near-net shape activities save any Co in the final engines. The best near net shape will do is reduce the amount of Co in the chips and minimize the recycle problems. To go to higher Co content to reduce the amount of superalloys processed to engine parts misses the point as <u>more</u> Co actually ends up in the engines.

2. Substitution is ongoing, owing to a strong driving force (10 X increase in price). Most attention has been paid to superalloys since this is the largest (%) consumption - but it is occurring across the board. The users do not appear to be especially motiviated by concerns about supply disruptions. Thus, I see no "contingency planning" for emergencies - only cost reduction drive, which will continue as long as the current price will prevail.

3. Substantial evidence now exists to indicate that reduction of cobalt by up to 50% in many alloys may be technically viable. The major obstacle, however, is (1) the time and resources required to generate required design data for critical components such as disks and (2) the expense of running extensive engine tests to verify the integrity of the component. In order to facilitate rapid implementation in the event of a cobalt shortage, the DoD should implement programs to qualify leaner Co disk alloys. This step may also result in a reduction of the price of cobalt.

3. Talks today indicate great success already achieved in replacing and reducing Co contents of high speed steels (Crucible CPM REX alloys) and magnet alloys (Schlabach's talk). There is little need for government assistance or sponsorship in these areas. Government stimulation is needed in accelerating Co substitution in superalloys for gas turbine engine applications. It is very costly and time consuming to prove out alloys applicability for engine uses.

3&4. I believe an important recommendation should be for the DOC to take strong measures to eliminate the adversary relationships that now exist between government & industry. Anti-trust laws, patents, protection of proprietary information are areas in need of complete overhaul and are far more important to accelerate progress in this country than any single technological development. More than anything else we need a climate that is conducive for the federal government to work cooperatively with private industry.

* I say amen to the above. A good place to start would be with the mining and metal producing industries.

SESSION III A COATINGS

QUESTIONS

1. What technological obstacles impede the otherwise economically favorable displacement of critical metals by coatings?

2. What currently economically unfavorable substitutions of coatings for critical metals are sufficiently promising for consideration for emergency substitution, such as a cutoff during a political embargo or wartime?

3. What specific approaches do you recommend to deal with these obstacles for inclusion in the report of the Department of Commerce to the Congress?

SAMPLE RESPONSES FROM 26 PARTICIPANTS

1. Technological obstacles impeding the displacement of critical metals by coatings include the lack of a universal method, or a group of universal techniques, for coating. Many of coatings are line of sight, i.e. spray, and ion beam. Others include clip coating whose economics restrict usage. Coating technology does exist, however, usage appears limited.

2. Coatings & claddings offer ready (immediate) substitution of surface treatment for bulk use of Cr, Co, etc. Cost of coatings & claddings obviously preclude such changes without other pressures, such as embargoes. Some long range effort should be initiated to improve coating technology.

2. Chromized-coated sheet as a replacement for 409 stainless steel failed commercially for economic reasons only. Chromized sheet as a replacement for 409 could save significant amounts of chromium for many applications.

3. There must be an assured market with adequate profit for a number of years, to encourage the capital expenditure necessary to build a production line to supply chromized sheet.

3. A possible role for government would be in promoting long term testing (e.g. use in selected government applications) combined with 1) a program to understand failure, when it occurs, in terms of mechanisms so that useful guidance can be provided for improving long-term reliability and 2) development of improved inspection methods & standards for quality control.

SESSION III B RAPID SOLIDIFICATION AND NEAR NET SHAPE

QUESTIONS

1. What properties of rapidly solidized metals and near net shape products make them attractive as alternates to conventional alloys with imported sources?

2. What market sectors will benefit most over the next ten years from the conservation and substitution of critical metals utilizing rapid solidification and near net shape processing technologies? Where are the major investment opportunities?

3. What are the major technical and institutional barriers or "choke points" in realizing the full technical potential from these processing technologies? For example:
   - In what ways can computer-aided design, processing and manufacture and inspection further enhance opportunities for conservation and substitution of critical metals utilizing these processing technologies?
   - In what ways will these processing technologies either enhance or limit the use of nondestructive evaluation methods for quality assurance?

4. What public policies, programs, or financial support are needed to assist producers, users, and designers in developing confidence in these processing technologies? For example:
   - How can alternate materials produced by these technologies be qualified for use without jeopardizing the patent interests of producers, or suppliers?

SAMPLE RESPONSES FROM 45 PARTICIPANTS

1. The tolerance of the realized HIP'd part must be close enough to the final shape such that the reduction in machining costs off-sets the increase in cost of the part because of the high cost of powder. The properties realized are usually equivalent to the conventional product when using conventional alloys. Therefore, the net gain must be in machining. The assumption made here is that "conventional" in the question refers to alloys that do not realize a special property gain due to RSR techniques.

* The PM approach does not seem to discuss problems of dirt, defects from trapped gas & air and other comtaminents.

1. Fine grain size, homogeneity, small second phase size, increased solid solubility, decreased machining costs, increased material utilization, increased ultrasonic inspection capability, increased volume percent of second phases, usually higher strength and ductility, increased toughness, better cutting tool performance, ability to replace certain elements such as W and Co with Mo which is domestically available, etc.

2. High alloy content, high technology alloys which are used in very demanding applications. Aerospace and gas turbine are probably the most obvious since the additional cost of the process is not a high proportion of the total component cost. Rapid solidification appears to have the most possibilities but the furthest to go. Near net shape appears to have more immediate payoffs.

2. These technologies often involve powder production. Therefore compacting equipment, high temperature melting equipment, controlled atmosphere equipment will be needed. Development work on high volume production of economical very pure powders is needed. No one will commit to using powdered metals unless they are assured of supplies at a reasonable price. Which comes first powder or market?
   Rapid solidification to produce strip & sheet also is a technology worth investigating because of the high capital cost of current rolling mills.

3. Rapid solidification and near-net HIP shape technology offer good possibilities for reducing the use of critical materials. Some work still needs to be done.
   a. CAD will be necessary for productive of as-HIP PM shapes on a routine basis.
   b. Further improvement in properties needs to be achieved; particularly LCF.
   c. Refractorless melting and processing needs to be developed to minimize possibility of defects.
   d. Near-net sonic capability needs to be developed.

   All areas will require continued government support to fully diffuse the PM as - HIP process.

4. These two processes should follow the normal road for new technology. I think that their contribution to the critical materials issue is indirect at best and should not be overly emphasized.

SESSION IV A TITANIUM

QUESTIONS

1. What specific technological developments might lead to significant reductions in the cost of titanium components, and/or expansion in its non aerospace use?

2. What aspect of titanium production-reduction, melting, or mill shape fabrication - is most likely to encounter future inadequacies which can result in significant shortages or price increases?

3. What obstacles impede preparation for emergency substitution through technological development, and what future steps to improve emergency substitution should be included in the recommendations which the Department of Commerce makes to Congress?

SAMPLE RESPONSES FROM 28 PARTICIPANTS

1. Expansion of non-aerospace uses will be directly tied to methods to produce Ti and Ti alloys much more economically. This means that methods to produce products directly from sponge must be developed which will yield a satisfactory product. Advances in two significant areas are necessary.
   a. high purity (low chloride and other contaminant) Ti powders must be made available (economically), in order to promote powder fabrication. Other methods of producing Ti powder (e.g. D-H) may work out as well - important points are cost and purity!
   b. homogenization (powder blending) processing technology must be developed (high sophistication and low cost) to promote the use of P/M processing.

   Summary - as long as we continue to use spherical Ti and Ti alloy powders (expensive) and fabrication techniques that are expensive, we can never realize a significant non-aerospace market.

1. Low cost production of Ti powder directly from ilmenite ore should lead to significant cost reduction. Near net shape parts utilizing P.M technology (CIP) to minimize machining should open doors for non aerospace application particularly in automotive engine parts such as connecting rods, wrist pins, valves.

1&2 The titanium technology, through production fabrication and alloy development, has been essentially controled by rigid specifications for material that will be flown and in many cases serve as rotating parts. In my own opinion this has precluded the use of resources to develop lower-cost Ti alloys for use in less critical applications such as pump and valve components for chemical plants. This situation is not likely to change in the near future, the aerospace industry continuing to set the stage for titanium technology and technological advances. In the event chromium and/or stainless steel should increase significantly in cost, new titanium technology might be forthcoming for corrosion resistant Ti alloy produced at low cost. Mr. Burte may be pleased to know that the Bureau of Mines has scheduled research for the production of titanium alloy powder by co-reduction of the chlorides.

2. The supply of rutile could be cut off by international activities. It is possible that Timet and other Ti producers would be almost wiped out of sponge for production of Ti tetrachloride. Since we have large deposits of ilmenite in the U.S. I believe we should make strides to use it. I understand that the Dow Process for production of $Ti\ Cl_4$ uses ilmenite effectively. This could be incorporated and the D-H electralytic or Timet electrolytic sponge processes should be exploited to cut costs. I think this is important since Titanium is the 9th most abundant material found in the earth's crust and it could be used effectively in emergencies of materials shortages.

3. Titanium should not be considered a critical material. The problem area with titanium, fluctuating supply, is economic and materials utilization oriented and should be solved by normal supply and demand techniques. I do think that recommending use of the stockpile to stabilize prices is a sound idea.

3. The major obstacle is cost. Neither we in industry, or the government, can afford to invent substitutes. We must stabilize the source through expanded market. I think the major thing the government and congress must do is not commit itself to a major program lightly, but follow through with it, or cancel it. They must have an alternate plan for subsidizing the expenditures, building the stockpile, etc.

SESSION IV A TANTALUM

QUESTIONS

1. Of the eight elements dealt with specifically in this workshop (chromium, cobalt, titanium, tantalum, molybdenum, nickel, vanadium, tungsten), where would you rank tantalum as a metal critical
   - To all industry?
   - To the defense industry?
   - To your industry? (specify industry)

   (One is most critical, eight is least critical)

2. If manganese, the platinum group metals, and tin were added to this list, what would your ranking be?

3. What obstacles impede preparation for emergency substitution through technological development, and what future steps to improve emergency substitution should be included in the recommendations which the Department of Commerce makes to Congress?

RESPONSES FROM 23 PARTICIPANTS TO QUESTIONS 1 & 2

		#1	#2	#3	#4	#5	#6	#7	#8	#9	#10
1.	Industry	4	2	2	2	-	-	2	1	-	-
	Defense	6	3	3	2	-	1	-	-	-	-
	Your Industry	5	4	-	-	1	1	-	-	-	-
2.	Industry	3	2	2	1	2	-	1	-	-	-
	Defense	4	4	1	1	-	1	-	-	-	-
	Your Industry	4	2	1	-	-	1	-	-	-	-

SAMPLE RESPONSES FROM 23 PARTICIPANTS

1. Ta and Ti are candidates for the most critical materials in the gas turbine industry. Unavailability of Ti would have the most serious impact since the compressor sections of most gas turbines are Ti base. Cutbacks in Ta would be significant, however, and Ta free superalloys would mean lower performance (TSFC) and/or higher maintenance costs.

3. There seems to be a variety of opinions as to the effect of Ta on properties and to the reasons behind these variations. Certainly, the Ta effect will vary depending on the alloy (content of all alloying elements). What is needed is some good baseline data on the role of Ta. At that point, we would be prepared to take appropriate steps to attack the problem. In the meantime, we ought to determine the role of Ta (structure vs properties) in superalloys.

3. Electronics applications has generally dictated extremely high purity Ta for best capacitance and therefore restricting efficient recycling of Ta scrap (e.g. that with slight quantity of Mo, or W). Perhaps it might be of some interest to review data and attempt development of electronics requiring less pure Ta.

SESSION IV B DOMESTIC METALS

QUESTIONS

1. Should the government take an active role in encouraging the use of domestic or near domestic metals as substitutes for critical metals?

2. Should the role of government be:
   a) limited to basic research?
   b) both basic research and development of new products?
   c) to carry new products through field demonstration?
   d) to encourage commercial development of substitutes for critical metals even if not presently economically justified?

3. Should government action:
   a) be limited to materials affecting national security?
   b) cover both strategic and general commercial products?
   c) be different for strategic and general commercial applications?

4. What steps to encourage the substitution of alloys using domestic or near domestic materials for those using critical metals should be included in the recommendations which the Department of Commerce makes to the Congress?

5. What role should the technical societies play to encourage the use of domestic or near domestic metals?

SAMPLE RESPONSES FROM 34 PARTICIPANTS

1. Twenty of the thirty four respondents answered this question positively, two negatively, three introduced caveats, and nine did not deal with this question.

1. Only if private sector participates voluntarily, projects are long-term, incentives are designed to expire on a certain date, or project proves economic or uneconomic by the certain date.

2. I think government role should be limited to basic research in so far as general usage products are concerned. Development of substitutions will depend entirely on economics. With respect to materials (alloys) used in national security applications superalloys etc., Government laboratories and research grants should be focused on the development of new materials that conserve critical materials.

3. At present government action has to be restricted to conservation and/or substitution of materials affecting national security. The economic forces will take care of the commercial sector. Government action should be two fold - a) encouragement of conservation through directives to companies involved in government contract supply to institute a conservation approach to the selection of materials involving critical materials (e.g. use of aluminum alloys in some corrosive environments instead of stainless steel); b) finance the basic research of alloy replacement rather than short term advantages of one element at a time to improve only a single metallurgical property.

3. Government action should be restricted to materials affecting national security. Government should supply guidelines for strategic materials used commercially. Supply and demand laws will restrict commercial requirements adequately. Some government funds should be spent in the commercial area to encourage reclamation of strategic elements to assure adequate supply.

4. A structure of beneficial tax treatment of expenses related to demonstration and implementation of new materials of reduced critical metal content and increased domestic or near domestic metal content, particularly with regard to qualification expenses.

4&5 The Tech Societies & Government had better get together and decide on the running rules (philosophy) to be used as a guide in formulating a policy and consequent programs. Programs aimed individually can range from partially effective, overall, to counterproductive in the "Big Picture."

SESSION V COMPOSITES

QUESTIONS

1. What technological obstacles impede the otherwise economically favorable substitution of critical metals by advanced engineering composite materials, such as graphite/resin, kevlar/resin, carbon/carbon, and carbon/aluminum, as examples?

2. What currently economically unfavorable examples of substitutions of critical metals by composites are sufficiently promising technically so that these uses can be pursued, should there be an emergency, such as the cutoff of critical metals during a political embargo or wartime?

3. What specific approaches do you recommend to deal with these technical obstacles so that these approaches can be included in the report that the Department of Commerce will submit to the Congress in October?

4. Some people believe that the most important factor inhibiting more rapid penetration of composite structures into the aerospace industry is a lack of broad industry experience with advanced composites. Because of this lack of industry experience, industry's lack of confidence in composites for use in primary aircraft structures is understandable. What actions, on a priority basis, should be taken in the next few years to improve that confidence level in composites in order to accelerate their use in the aerospace industry in the 1980's and allow for lower costs as volume of use increases?

Please answer any one question about which you are most knowledgeable. Also, questions 1, 2 and 3 can be answered as a group of related questions.

SAMPLE RESPONSES FROM 65 PARTICIPANTS

1. I feel that composites should replace metallic materials only where there is an economic driving force. The nature of composites only permit them to be substituted for materials which are not necessarily "critical" materials i.e. aluminum & titanium. Our most critical materials are Cr & Co and there is no potential for composites to replace these materials. Composites will realize the share of the market they deserve on their own merits and force feeding of these materials by Uncle Sam is not warranted.

1. A major technological obstacle is investment in capital equipment for manufacturing that cannot be converted to manufacture of composite structures i.e. forming presses, metal machining tools, etc.

1.a. Obstacles are scale size of plant capacity to produce composite materials in large quantities but this reluctance is based on an unsure assessment of the demand for the product, i.e. the chicken & egg circularity.
b. Current production work is too labor intensive; lack of sufficient automation in the production process.
c. Quality control is difficult because it involves too many intermediate materials & supplies. This makes certification more difficult.

2. The use of composites in primary airframe structures.

3. Resins need to be developed which are fast curing, low cost, moisture resistant, etc. Carbon/carbon composites need improved densification techniques. All composites need extensive materials with low labor costs using relatively simple processing methods & equipment. Quality assurance testing and control techniques must be developed which are part of the manufacturing process and which are simple, fast and reliable.

3. Certainly many automotive applications would appear to be currently favorable, but uneconomical. To help accelerate these applications, more rapid tax writeoffs for installation of new mfg. equipment appears to be in order. Perhaps the industry could select specific parts for use in primary aircraft structures for demonstration so that experience could be gained. It looks like an industry-government cooperative effort in this direction will be required.

4. I don't agree with the premise stated in the 1st sentence. Composites are being introduced into military aircraft much more rapidly than has been the case with most metal alloys in the past. No additional impetus has to be provided to accelerate their use - high fuel costs in the case of commercial aircraft and demands for high performance in military aircraft are sufficient driving forces in themselves to encourage rapid conversion to composites.

SESSION VI INFORMATION

QUESTIONS

1. In the event of a total chromium cutoff, what information would you need to make an emergency substitution in your products?

2. Is this information currently available? Is it accessible?

3. What would be your concept of an information system to provide data for substitution and conservation in an emergency cutoff of supply?

SAMPLE RESPONSES FROM 44 PARTICIPANTS

Each of the first three sets of responses were provided by an individual participant.

1. None. We have completed our alloy steel (Cr-free) test program.

2. ---------

3. I cannot imagine one that could be used without an evaluation procedure by each user; therefore data must include service use data and processing details.

1. The categories of materials affected include:
   a) low alloysteels for shafts, bearings
   b) stainless steels (300, 400 series)
   c) superalloy blades, vanes, disks, sheet alloys

   Information required would be of the nature of
   a) alternate elemental additions to give equal hardenability
   b) design info (general) on Fe-Al-Mn, etc.
   c) corrosion resistant coatings with improved durability

2. Category a data is available & accessible; other data may exist in part, but they represent areas where substitution/replacement is simply not practical. What is really needed is the extent of reallocation possible to divert Cr away from cosmetic applications of stainless steels to defense-related superalloys.

3. Existing system adequate.

1. Assume that there would be a priority system initiated under government control (as in World War II and Korea). We would need to know as soon as possible the priority position for stainless steels relative to our particular usage. This would afford time to redesign and modify existing components.

2. No, yes.

3. I believe that permitted freedom of action, and minimizing the bureaucracy, emergency substitutions could be implemented without too much difficulty with the knowledge and talent already available. Provided we don't elect the route of becoming totally philosophical and make the same mistake of the ancient Athenians.

The following responses were provided by individual participants.

1. I would like the following info in any cutoff.
   a) Eliminate/avoid confustion
   b) Careful Government response and directives with pre warning of
      1) what is magnitude and direction of allocations military U.S. Consumer, U.S. industrial
      2) what is purity of any large governmental/industrial stockpile and allocation of distribution
      3) whether price controls (temporary I hope) would have to be imposed over short term and long term.

3. No comment on chromium but a final thought is that if a stockpile of substitutional technology is established then apart from helping substitute alternate materials it would be of considerable help in improving the productivity of the country.

TABLE IV

FINDINGS AND RECOMMENDATIONS

The findings and recommendations given below are not intended to be exhaustive. They have been drawn almost entirely from the results of the brainwriting exercises. Consequently, important points made in the papers will not appear among the findings and recommendations.

The terms displacement and emergency substitution which are used in these statements have the following meanings. Displacement occurs when technological and economic factors dictate the exchange of one material for another. Emergency substitution occurs when one material is exchanged for another as a result of a shortage caused by geopolitical factors, although the exchange is unfavorable technologically and economically.

To simplify your evaluation of the findings and recommendations, they are organized according to the topic of each session held during the workshop. In addition, some of the findings and recommendations have been combined into a general category. Separation according to topic will permit you to quickly identify those topics which you wish to evaluate, and also those which you do not wish to evaluate. We prefer that you evaluate all of the findings and recommendations within a particular topic (e.g. titanium), though we do not insist that you do so. The evaluation procedure is explained on the rating form.

CHROMIUM

Findings

1. There may be substitutes for chrome bearing materials with acceptable mechanical properties, but information about melting, casting, working, machining, joining, and heat treating is needed, in addition to mechanical properties.

2. Given current technological knowledge, the high temperature corrosion and oxidation resistance provided by by chromium makes substitution for it in these applications difficult, if not impossible.

3. It is difficult to justify large industrial R&D expenditures on substitutes at times of ready availability and low cost of a critical material. It is also difficult to predict if and when a material will become unavailable. In such instances development of information on emergency substitution for, and displacement of, chromium will require substantial funding from the Government. Corporations by themselves will not fund such work, nor give it the necessary priority to have the data available for use by anyone at some time in the future.

Recommendations

4. To ensure the development of process technology for applications of special national interest, the U.S. Government may need to generate special incentives, including the funding of research and dissemination of the results. New alloy systems could be developed based on manganese and aluminum, and iron and aluminum, which could displace chromium based alloys.

5. For a "technology stockpile" to be effective in an emergency, a stockpile of capital equipment to implement the technologies may also be required. This is costly. Government financing, or joint Government-private sector involvement, would be required to create a real "technology stockpile."

6. The cost and effort required to qualify a material which would displace a critical material (chromium) is a barrier to its displacement. These procedures should be evaluated with the objective of reducing the cost of qualification where possible to encourage displacement.

7. In some cases, codes require a high chromium alloy when a lower chromium alloy or even a nonmetal would function equally well. Alloy specifications codes should be reevaluated by the originating organization in light of current technology, to determine if high chromium steels are indeed needed for the current applications. Appropriate technological information should be provided to back up recommended modifications.

COBALT

Findings

8. The sharp rise in the price of cobalt has stimulated its displacement in some high temperature and wear-resistant applications.

9. There is a wide spectrum of magnetic alloys where substitution to reduce, or eliminate, the use of cobalt is both technically and economically possible.

Recommendations

10. Emergency substitution for cobalt in military jet engines involves lengthy testing and qualification requirements. Back-up alloys should be prequalified for use in emergencies, if they can provide "almost as good" performance.

11. Although cobalt is known to be an important constituent of high temperature superalloys, its exact role as an alloying agent is uncertain. Additional R&D is needed for the study of complex superalloy systems and tool steels in order that the development of substitutes can proceed beyond a purely empirical point.

12. Attention should be given to the development of non cobalt bonding materials that would function in current machines with little or no change in operational procedure.

TANTALUM

Findings

13. Of the four metals considered in this workshop, tantalum is likely to be the most critical from the viewpoint of substitution. Its criticality may increase with the advent of single crystal blades in jet engines.

14. In the electronics industry, tantalum ranks third in degree of concern, behind cobalt and platinum metals.

15. The high price of tantalum provides a strong driving force for its displacement in certain applications.

16. Considering the small amount of tantalum which is recycled now, and its price, opportunities to recycle more should be indentified.

Recommendations

17. The exact role of tantalum as an alloying agent is presently not well understood. Further R&D should be directed to clarifying the role of tantalum (structure versus properties) in superalloys.

TITANIUM

Findings

18. The concern about disruptions or potential disruptions of the availability of titanium components in the United States is different from the concern with the other metals considered at this workshop. Domestic ilmenite (rather than foreign rutile) could serve as a source of titanium in an emergency, if pilot production is undertaken. However, to exploit ilmenite domestically, attention needs to be paid to ferric chloride pollution.

19. There is no current agreement as to which step-sponge production, melting, or mill shape fabrication is the choke point causing shortages, or long lead times, for titanium production.

20. Expansion of the range of uses of titanium through cost reduction, agressive exploration of new markets, and possibly improved properties are the most appropriate routes to ensure a more stable supply of titanium. There are technological options worth pursuing toward these objectives.

21. New alloys are needed which are tailored for specific uses.

Recommendations

22. New large capacity electrowinning plants employing modern technology to reduce production costs are needed. The titanium industry should be given a liberal tax credit, or write offs of equipment and facilities, in order to encourage investment in the electrowinning process and other approaches in view of potentially adverse market conditions.

23. The current costs of titanium and titanium alloys are relatively high. The development of energy efficient alternative reduction processes (such as direct reduction from chemical precursor to alloy powder) that minimize the number of process steps and thereby provide more economical titanium should be pursued.

24. The titanium product shortage is not due to lack of installed capacity but to lack of long range commitments on the part of users which would allow better scheduling. Multi-year procurement commitments are needed and better and more stable forecasts of needs.

25. Better utilization of titanium can be realized through the use of improved scrap reclamation.

COMPOSITES

Findings

26. Although organic matrix composites will not play a major role as replacements for high temperature critical materials in aerospace in the 1980's, they are a new class of high performance materials which will compete with the more conventional materials (e.g., aluminum, steel, titanium) in aerospace. Their use will result in a weight reduction of about 20 percent in aircraft which will allow for downsizing of engines and a decrease in the use of critical materials (e.g., cobalt, tantalum) in aircraft engines in the 1980's.

27. Major technological obstacles to using composites as substitutes include elevated temperature performance; both for moderately elevated temperatures (a few hundred degrees C) and high temperatures (vicinity of 1000°C). Further development is needed to raise the temperature ceiling of polymeric materials for moderately elevated temperature application.

28.. Major technological obstacles in substitution for critical metals in high temperature applications exist. Metal matrix composites have the potential for achieving good high temperature performance. Therefore, metal matrix composites may have the capability to displace some superalloys containing Co and Cr. Metal matrix composites is an area needing continued development.

29. While composite materials manufacturing processes are not considered prohibitively labor intensive in the aerospace industry, they are currently sufficiently labor intensive to pose economic problems for application in the automotive and other non aerospace industries.

30. Quality control procedures for composite materials fabrication must be incorporated in the fabrication processes. Current NDE procedures are generally inapplicable to the inspection of completed complex composite structures and components.

31. There is a very large body of knowledge about the resistance of metal alloys to specific and troublesome environments. There are good possibilities for using composites instead of stainless and other corrosion resistant special alloys in such troublesome environments. For example, polymer based composites with graphite or other reinforcements can replace critical metals used in extremely corrosive environments, such as in chemical production and in environmental and maritime service.

Recommendations

32. The extension of usefulness of metal matrix composites in elevated temperature service conditions could be a valuable contribution in relieving our dependence on chromium and other critical materials. Research and development in this field should be pursued.

33. The more rapid and widespread use of new and improved fibers and polymeric matrix materials would be accelerated by the orderly compilation and analysis of their physical and mechanical properties over a broad range of temperatures and environments.

34. A big factor involved in achieving greater use of composites in aircraft is the education of designers to consider materials in the early stages of design. To this end, professional engineering organizations should encourage universities to emphasize all materials, not only metals, more heavily in Mechanical Engineering curricula since this is where most design engineers are educated.

35. Development of improved NDE procedures for composites should be pursued for use in control of processing, inspection after production and assembly, and inspection after service.

Findings

36. The increased alloying levels and homogeneity of RST powder appear to be unusually attractive in disc alloy development--particularly when coupled with near net shape superplastic forming technology.

37. Gas atomization is one particularly promising RS technology. Other methods may also have commercial potential, for instance, some version of melt spinning.

38. Use of abundant materials such as Al and Fe in RST could reduce our vulnerability to foreign suppliers of Co and Cr, but achieving higher performance is probably an even greater reason for developing RST materials.

39. Highly dispersed precipitates and increased solubilities of alloying elements are definite advantages of RST. However, further analysis needs to be performed to correlate particle size to strength and toughness improvements, and to establish the comparative advantage of RST to the traditional hot worked metals.

40. One problem with powder technology has been reproducibility and quality control of the powder.

41. Improved testing procedures, especially NDE methods, will expand the use of near net shape production processes.

42. Cleaner powders are essential for increased use of near net shape production processes.

Recommendations

43. A National Materials and Minerals Policy should provide tax incentives for investing in commercially-scaled RS technologies.

44. Support mechanisms should be considered for design trade-off, actual part evaluation, and test studies to provide designer and producer confidence in the new technologies and generate the data needed for new designs.

45. Studies in phase equilibrium relationships, structure-property relationships, and solidification mechanisms should be stimulated through federal research support.

COATINGS

Findings

46. Good opportunities exist for conserving large amounts of critical materials through the use of coatings, claddings, and various forms of surface alloying. Many such applications are in use today and others are economically promising. There is reluctance to take the risk of putting these coatings into active service in cases where failure of the coating could cause hazard (e.g., possible jet engine failure) or large economic liability (e.g., possible failure of valve seats in automobile engines). Uncertainty about long-term reliability and lack of dependable inspection procedures for quality control to ensure long-term reliability are impeding the introduction of coatings in some applications.

47. One particularly promising coating is surface alloying. It appears to offer a great variety of coating capabilities without fear of spalling or edge effects. One problem is that properties necessary in the core material may be affected unpredictably, or may actually be degraded by the application method (higher temperatures).

48. Chromized-coated sheet as a replacement for stainless steel failed commercially for economic reasons only.Chromized sheet would serve as a substitute for stainless steel in many applications and would conserve at least 50% of the chromium now required for stainless steel.

49. There are incentives, both economic and technical, for coating corrosion- or wear-resistant materials to enhance their surface properties. What is needed particularly is more work (research) to give confidence that we can coat mild steel or other nonresistant materials and use these coated materials to displace the highly alloyed materials which require critical materials. This should ultimately be economically advantageous in many applications.

Recommendations

50. To extend product life Government should promote long term testing, (e.g., of uses in selected Government applications), and a program to understand failure in terms of mechanisms, when it occurs, so that useful guidance can be provided for improving long-term reliability of coated materials.

DOMESTIC AND NEAR DOMESTIC MATERIALS

Finding

51. There are a number of technical opportunities that might be developed and expanded in order to utilize domestically available elements such an nickel, tungsten, vanadium, and molybdenum to substitute, at least partially, for chromium, cobalt, tantalum, and titanium.

Recommendations

52. Technical meetings and workshops are needed periodically to focus attention on opportunities for utilization of domestically available materials in place of critical imported materials.

53. The Government should see that adequate substitutes are developed emphasizing domestic materials and available for use when needed. Naturally the cost would be a factor for commercial use, but strategic use is not as dependent on cost.

54. Government procurement should be employed to increase the use of domestic metals or near domestic metals while decreasing the use of critical metals in aerospace equipment.

55. Full depreciation in three years or less should be permitted for those fixed capital expenditures which would increase the availability of domestic metals or near domestic metals that are substitutes for critical metals.

56. Full depreciation in three years or less should be permitted for those fixed capital expenditures which would lead to reclamation of critical metals.

57. The Government should, through some incentive, encourage the development of processes for the reclamation of critical metals wherever possible. Such technologies have been under consideration for years, but most are not economically attractive to industry without incentives.

INFORMATION STOCKPILE (SUBSTITUTION PREPAREDNESS)

Findings

58. The information needed for substitution of chromium, as an example, would depend on the warning time prior to the cut-off. If cut-off is immediate, the substitute material for the component will have to be a material which has already been qualified for the application. If information is available in advance, the effect of downgrading can be minimized.

59. Emergency substitution would require data on alloys derived from reprocessed material of doubtful origin. Thus, knowledge of the impurity effects would be needed.

60. Good data are severely limited for chromium-free alloys which could be used as substitutes under demanding conditions.

61. Current information systems do not often record the properties of non-standard grades.

62. Another extremely important part of the data required for emergency substitution would be the corrosion resistance in hostile environments.

63. Information concerning coatings that might be used to lower chromium use in materials would be desirable.

64. Chromium cannot be removed from nickel base superalloys currently used in hot turbine applications on the basis of present information. It may be possible to use claddings to substitute for some of the chromium if adequate information were available.

65. The ceramic technology offers long range potential for increased performance (e.g. in adiabatic diesels) and decreased dependence on critical metals.

Recommendations

66. A human stockpile of information should be organized which could be employed immediately during an emergency.

67. Basic research on the role which critical metals play in alloys would provide information that would be used in the normal materials displacement process where compound performance is a key part. This information would also guide effective substitution in an emergency.

68. The information stockpile should include as many alternate approaches as possible including substitution, processing, recycling, and alternate sources. It should be tailored to the specific applications and the properties required.

69. Comprehensive examination of the information developed on uses and substitutions of critical metals, such as the NMAB report on chromium, should be conducted periodically. High priority should be given to this particular metal. Useful information would include basic property data, fabrication techniques and requirements, and test results obtained in service environments.

70. Existing organizations that collect, stockpile, and disseminate information could stockpile information organized about each of the critical metals.

71. Mechanisms should be developed to induce the disclosure of proprietary information on properties of substitutes for critical metals during an emergency.

GENERAL

Finding

72. The basic role of Government is to perform critical basic research that may be too costly and/or too risky for private industry alone (long range/high risk).

Recommendations

73. Economic incentives for the displacement of some critical metals are weak. Anti trust limitations on cooperative research should be examined to determine whether they can be waived to encourage the development of substitutes for critical metals such as chromium.

74. Priorities which would be invoked for allocating critical metals in an emergency should be made known to all concerned industries, to encourage rational planning for emergency substitution.

75. DOC recommendations should include Government funding of special alloy development and the building of a data base containing the resulting information for use during an emergency. Primary attention should be given to the most critical oxidation and corrosion resistant applications. Likewise, data should also be organized for applications where substitution and conservation are not economical under normal conditions,such as with heat teated steels.

76. The development of conservation options cannot be justified by industry solely as a hedge against possible periodic shortages because the cost of industrial R&D, and its implementation, must be justified by the return on investment regardless of shortage considerations. Investment in such options purely as a protection against future potential shortages is a Government responsibility.

77. The Government is providing support for critical metals conservation in aerospace materials, i.e., cobalt, through established funding agencies. Large savings of critical metals may be possible in commercial application, but industry may be unable to support such advanced programs. After certain processes with limited aerospace and military application have been shown to be viable, the Government may have to act as "champion" for continuing development and pilot utilization. Methods of providing support would have to be established.

TABLE V

Rating Form

This rating form is to be used in evaluating the findings and recommendations. You may agree strongly, agree, disagree, or supply a modified statement in evaluating the findings. In evaluating the findings simply check ( ) the preferred response. Recommendations are to be evaluated for importance, effectiveness, and ease of implementation. In evaluating the recommendations, enter the number of your preferred response. For example, enter (4) if you regard a recommendation as being of Minor Importance. The three rating scales for the recommendations are given below. If you disagree with a recommendation simply indicate your disagreement with a check ( ), and if you choose to do so supply a statement. Please return this rating form in the enclosed envelope by July 10.

IMPORTANCE

1. Of Major Importance
2. Of Moderate Importance
3. Of Limited Importance
4. Of Minor Importance
5. Of No Importance

EFFECTIVENESS

1. Very Effective
2. Moderately Effective
3. Possibly Effective
4. Probably not Effective
5. Would not be Effective

EASE OF IMPLEMENTATION

1. Will certainly be implemented through private action alone.
2. Would be implemented through private sector actions with appropriate changes in public policy.
3. Could be implemented through private sector action alone.
4. Is unlikely to be implemented through private sector action without appropriate changes in public policy.
5. Would not be implemented in the forseeable future through private sector action even with appropriate changes in public policy.

	FOR EVALUATING FINDINGS.				FOR EVALUATING RECOMMENDATIONS			
ITEM NUMBER	AGREE STRONGLY	AGREE	DISAGREE	MODIFIED STATEMENT SUPPLIED	IMPORT-ANCE	EFFECTIVE-NESS	EASE OF IMPLEMEN-TATION	DISAGREE (SUPPLY STATEMENT IF DESIRED)
CHROMIUM								
1.	____	____	____	____				
2.	____	____	____	____				
3.	____	____	____	____				
4.					____	____	____	____
5.					____	____	____	____
6.					____	____	____	____
7.					____	____	____	____
COBALT								
8.	____	____	____	____				
9.	____	____	____	____				
10.					____	____	____	____
11.					____	____	____	____
12.					____	____	____	____
TANTALUM								
13.	____	____	____	____				
14.	____	____	____	____				
15.	____	____	____	____				
16.	____	____	____	____				
17.					____	____	____	____
TITANIUM								
18.	____	____	____	____				
19.	____	____	____	____				
20.	____	____	____	____				
21.	____	____	____	____				
22.					____	____	____	____
23.					____	____	____	____
24.					____	____	____	____
25.					____	____	____	____
COMPOSITES								
26.	____	____	____	____				
27.	____	____	____	____				
28.	____	____	____	____				
29.	____	____	____	____				

30.
31.
32.
33.
34.
35.

RAPID SOLID-
IFICATION

36.
37.
38.
39.
40.
41.
42.
43.
44.
45.

COATINGS

46.
47.
48.
49.
50.

DOMESTIC AND
NEAR DOMESTIC
MATERIALS

51.
52.
53.
54.
55.
56.
57.

INFORMATION FOR EMERGENCY
EMERGENCY
SUBSTITUTION

58.
59.
60.
61.
62.
63.
64.
65.
66.
67.
68.
69.
70.
71.

GENERAL

72.
73.
74.
75.
76.
77.

TABLE VI

NUMBER OF RESPONDENTS ASSIGNING EACH POSSIBLE RATING TO THE FINDINGS

ITEM NUMBER	STRONGLY AGREE	AGREE	DISAGREE	MODIFIED STATEMENT WAS SUPPLIED
CHROMIUM				
1.	17	57	3	1
2.	33	38	8	0
3.	32	44	5	2
COBALT				
8.	40	31	2	1
9.	24	40	3	1
TANTALUM				
13.	12	27	16	0
14.	4	37	3	0
15.	25	29	2	0
16.	17	34	3	0
TITANIUM				
18.	17	31	4	1
19.	5	35	13	2
20.	19	33	6	0
21.	10	36	10	0
COMPOSITES				
26.	23	30	4	1
27.	16	36	5	0
28.	23	32	5	0
29.	18	30	7	1
30.	13	33	5	1
31.	12	30	6	2
RAPID SOLID-IFICATION				
36.	15	39	5	1
37.	11	46	0	0
38.	14	35	7	1
39.	19	36	1	0
40.	17	34	3	2
41.	7	42	5	1
42.	20	34	2	1
COATINGS				
46.	26	36	2	0
47.	13	44	4	0
48.	9	26	11	2
49.	25	30	3	1
DOMESTIC AND NEAR DOMESTIC MATERIALS				
51.	33	29	0	1

INFORMATION FOR EMERGENCY SUBSTITUTION				
58.	28	33	2	0
59.	15	44	1	1
60.	18	36	3	1
61.	14	42	2	0
62.	19	42	0	0
63.	16	44	2	0
64.	5	47	8	0
65.	9	45	6	0
GENERAL				
72.	41	19	15	4

TABLE VII

NUMBER OF RESPONDENTS ASSIGNING EACH POSSIBLE RATING TO THE CANDIDATE RECOMMENDATIONS

ITEM NUMBER	IMPORTANCE					EFFECTIVENESS					MEANS OF IMPLEMENTATION					DISAGREE WITH STRUCTURE OF STATEMENT
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	
CHROMIUM																
4.	38	31	7	1	1	19	32	19	6	1	1	7	8	49	11	2
5.	14	25	19	9	1	9	16	29	12	3	0	5	5	33	24	7
6.	40	18	12	4	1	19	23	20	9	2	0	15	15	30	13	4
7.	39	32	7	1	1	24	39	10	3	1	7	20	20	24	5	1
COBALT																
10.	42	23	3	2	0	24	34	8	1	0	3	10	17	30	7	1
11.	29	26	11	0	0	17	27	19	1	0	6	14	15	25	4	5
12.	16	23	18	3	1	12	20	23	3	1	11	7	27	13	3	4
TANTALUM																
17.	23	22	6	0	0	10	20	13	1	1	2	8	12	19	7	5
TITANIUM																
22.	22	15	10	0	0	13	15	16	2	0	1	9	7	26	2	6
23.	27	15	7	1	0	21	11	14	2	0	5	6	15	21	1	1
24.	22	18	4	1	0	14	21	7	1	0	1	12	5	21	4	7
25.	10	19	15	4	0	11	18	15	3	0	6	4	22	13	2	2
COMPOSITES																
32.	22	27	8	2	0	11	23	18	4	0	3	7	18	23	6	1
33.	17	27	10	3	0	13	29	9	4	0	3	7	22	16	7	1
34.	25	20	7	3	0	22	15	13	3	0	6	11	23	7	4	3
35.	25	25	3	0	1	19	26	5	1	0	6	7	28	7	3	0
RAPID SOLID-IFICATION																
43.	13	18	9	1	1	8	16	14	3	1	1	10	6	20	3	14
44.	19	19	6	1	1	14	18	12	1	2	4	4	14	17	5	4
45.	23	23	3	2	1	17	23	10	0	1	1	12	3	26	7	4
COATINGS																
50.	26	22	9	2	0	20	23	13	3	0	0	12	11	27	7	2
DOMESTIC AND NEAR DOMESTIC MATERIALS																
52.	23	26	14	0	0	19	25	17	1	0	6	15	19	19	2	1
53.	27	19	4	2	1	15	23	12	2	1	1	6	2	33	8	7
54.	11	15	13	4	1	8	15	12	7	1	0	6	1	26	10	14
55.	14	26	3	1	0	13	22	6	2	0	1	14	1	22	3	13
56.	17	26	4	1	0	14	25	8	1	0	0	17	3	22	7	10
57.	23	26	4	0	0	20	23	9	1	0	1	11	0	34	5	8
INFORMATION FOR EMERGENCY SUBSTITUTION																
66.	31	20	4	1	1	23	23	8	0	1	1	11	8	25	11	1
67.	22	26	9	1	0	18	23	13	1	0	0	9	7	28	9	2
68.	34	20	4	1	0	23	26	7	0	0	0	12	9	29	6	0
69.	26	28	4	3	0	17	32	7	1	0	2	13	8	26	7	0
70.	25	29	5	1	0	22	30	6	0	0	4	12	12	25	5	1
71.	18	19	11	5	0	11	17	16	7	1	0	4	4	29	16	4

GENERAL

73.	22	24	9	4	0	11	26	16	5	0	0	8	3	33	11	6
74.	36	25	5	0	0	19	24	9	3	0	2	13	4	33	12	0
75.	32	18	6	3	0	21	27	6	3	2	0	10	2	30	15	7
76.	25	14	7	2	1	17	17	9	2	1	0	6	4	22	16	16
77.	25	26	5	2	0	20	25	9	3	0	0	7	1	33	15	6

WRITTEN SUBMISSION TO WORKSHOP

James I. Mueller, President
American Ceramic Society

The American Ceramic Society, Inc.

JAMES I. MUELLER
President

Reply To
Ceramic Engineering Division, FB-10
University of Washington
Seattle, Washington 98195
Telephone (206) 543-2613

June 9, 1981

Dr. Allen Gray, Chairman
Department of Commerce Workshop
"Potential Role of Advanced Materials in the
Aerospace Industry"
Vanderbilt University
P. O. Box 1553, Station B
Nashville, Tennessee 37235

Dear Dr. Gray:

Having reviewed the workshop program without the benefit of the depth of subject matter to be covered by your speakers, I would like to briefly describe a few, non-inclusive activities of the ceramic community appropriate to the general subject of the workshop. These would, by their nature, fall in the category of substitution for critical materials.

COATINGS

Ceramic coatings have a long history for the protection of metal surfaces from chemical corrosion at room and moderately elevated temperatures. The use of alumide coatings on refractory metals with low chromium contact provides a protective layer of aluminum oxide which offers effectiveness in some application similar to the chromium oxide layer. Similar results have been obtained in the past using silicide coatings.

Thin oxide coatings on low grade steels are also under development as a measure to reduce our dependence upon stainless steels. These coatings are obtained by the hydrolization of an organometallic and the subsequent controlled polymerization of the hydrated molecules. The application of these liquid organometallics to any complex metal stage is fairly simple and viscosity control enables control of the coating thickness. Individual, multiple oxide or graded changes in composition are possible and the moderately low temperature processing makes them attractive from an energy viewpoint.

The recent development of chemical vapor deposition of oxides, nitrides, silicides and other corrosion-resistent/retardant coatings also offer a wide spectrum of possibilities.

COMPOSITES

Undoubtedly, much will be covered on the utilization of glass, carbon and possible aluminum oxide fibers in various matrices. Improvements in the understanding and properteis of these fibers continue to be of interest to a substantial number of ceramists. Newer ceramic fibers are under development and one in particular is worthy of note. Several companies have introduced fibers of silicon carbide which offer possibilities for use in room and elevated temperature applications. These are available as monofilaments and as two and three dimensional woven fabrics or as a felt. The results of laboratory studies utilizing these fibers in aluminum, beryllium and ceramic matrices are extremely interesting and certainly worthy of further study and scale-up.

Studies of ceramic matrix composites are infantile relative to those using polymeric and metal matrices. Work is progressing on the use of both fibrous and particulate reinforcement with long term possibilities seen in each. An example of the latter is the use of a phase transformation "toughener" material, such as zirocnium oxide, in normally monolithic ceramics.

One system to receive considerable attention and some use has been the carbon-carbon composites. Although their strength to weight ratios have been recognized their inability to withstand oxidation at elevated temperatures have limited the use in many areas. The recent success of a silicon carbide coated carbon-carbon composite as the nose-cap and wing leading edge components of the space shuttle orbiter gives some evidence of the future applicability of this material--especially since improved coatings and processing are available--including chemical vapor deposition.

MONOLITHIC CERAMICS

The past few years has seen a remarkable interest and improvement in the so-called advanced ceramics--primarily the silicon-based materials namely alpha silicon carbide and silicon nitride. One of the primary purposes of the DARPA program initiated in 1971 for the development of ceramics for the gas turbine engines was the search for a substitute for strategic materials. Considerable progress has been made in these materials with the aid of substantial funding from several federal agencies. The rate of progress in this country over the past few years has not kept pace with those of our international colleagues, principally from W. Germany and Japan. It is my personal belief that the reason for this has been the lack of a coordinated program for the improvement of materials processing and properties. These basic aspects have received but a fraction of our support level for these programs, the remainder being allocated to develop associated hardware which cannot be utilized until a satisfactory engine material is commercially available, ideally from more than a single source.

A considerable effort must be made, if we are to be competitive in this area and the hour glass (with its silicon-based sand) is rapidly running down. These ceramic materials and others do offer a meaningful potential for substitution but all involved must recognize that the development of a new engineering material--be it metallic, organic or ceramic--to its full application takes more than a decade.

DESIGN

Structural design with brittle and composite materials was nearly dormant since the days of building stone, brick, cast iron and the advent of reinforced concrete. This has resulted in numerous generations of design engineers who have worked only with ductile materials whose properties were for the most part isotropic. The continual experience with these types of materials was believed to have resulted in a prejudicial bias among designers regarding their possible utilization of composite and brittle materials. In 1976, both RPI and the University of Washington, with support from NASA, established academic and research programs to improve design methodology and understanding in the use of composite materials and brittle (ceramic) materials, respectively, in structural application. Each of the programs has proven successful educational experiences for young engineers. There still remains a substantial segment of engineering designers who must accept the design methodologies unique to each of these classes of materials if they are to be utilized in substitution for those critical metals which are the subject of this workshop.

Engineering design always includes iteration based upon conventional trade-offs. The substitution of non-common materials, be they coatings, composites or ceramics, will require a true understanding of all materials plus the ability and willingness to develop truly interdisciplinary communication with all involved. This workshop should stress the need of such an understanding.

Sincerely yours,

James I. Mueller
President

JIM/cm
cc: John B. Wachtman, Jr.
Arthur L. Friedberg

NBS-114A (REV. 2-80)

U.S. DEPT. OF COMM. **BIBLIOGRAPHIC DATA SHEET** (See instructions)	1. PUBLICATION OR REPORT NO. NBSIR 82-2495	2. Performing Organ. Report No.	3. Publication Date April 1982

4. TITLE AND SUBTITLE

CONSERVATION AND SUBSTITUTION TECHNOLOGY FOR CRITICAL MATERIALS--Proceedings of Public Workshop sponsored by U.S. Department of Commerce/National Bureau of Standards and U.S. Department of Interior/Bureau of Mines. VOLUME II.

5. AUTHOR(S)

Allen G. Gray

6. PERFORMING ORGANIZATION (If joint or other than NBS, see instructions)

NATIONAL BUREAU OF STANDARDS
DEPARTMENT OF COMMERCE
WASHINGTON, D.C. 20234

7. Contract/Grant No.

8. Type of Report & Period Covered

9. SPONSORING ORGANIZATION NAME AND COMPLETE ADDRESS (Street, City, State, ZIP)

Department of Commerce
National Bureau of Standards
Washington, DC 20234

and

Department of the Interior
Bureau of Mines
Washington, DC 20241

10. SUPPLEMENTARY NOTES

☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

11. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here)

The United States is highly vulnerable to problems in supply of critical and strategic materials and it is recognized that there is a whole spectrum of options for responding to such crises. While a number of supply oriented options are under study by various groups, the focus of this Workshop was on the technical options.

The Workshop was held principally to develop information for the report required by the Department of Commerce, but should also be useful to the other agencies in their responsibilities. The DoC report is supposed to identify a materials needs case related to national security, economic well-being, and industrial productivity, to assess critical materials needs, and to recommend programs to meet these needs.

12. KEY WORDS (Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons)

Critical materials; strategic materials; conservation; substitution; chromium; cobalt; titanium; tantalum.

13. AVAILABILITY

[X] Unlimited
☐ For Official Distribution. Do Not Release to NTIS
☐ Order From Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.
[X] Order From National Technical Information Service (NTIS), Springfield, VA. 22161

14. NO. OF PRINTED PAGES

579

15. Price

$40.50

USCOMM-DC 6043-P80

U.S. GOVERNMENT PRINTING OFFICE: 1982-360-997/2096